BAMBOO REINFORCED CONCRETE BEAMS AND SLABS

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VELAGA NARAYANA RAO

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This is to certify that this work on 'Bamboo Reinforced Concrete Beams and Slabs' has been carried out under my supervision and that it has not been submitted else where for a degree.

16/7/79

July, 1979

(Dr. Sri Rangasai Adidam)
Assistant Professor
Department of Civil Engineering
Indian Institute of Technology, Kanpur

POST GRADUATE OFFICE
This thesis has been approved for the award of the Degree of Master of Technology (M.Tech.) in accordance with the regulations of the Indian Institute of Technology Kanpur
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NOTATIONS

A_b	=	Area of bamboo reinforcement
b	=	Width of the section
C	=	Compressive force
C_c	=	Creep coefficient
d	=	Effective depth of tension reinforcement
E_b	=	Modulus of elasticity of bamboo
E_c	=	Static secant modulus of elasticity of concrete
E_{cb}	=	Modulus of elasticity of the composite
F_b	=	Stress in bamboo in tension
F_c	=	Compressive stress in concrete
F_{ct}	=	Tensile stress in concrete
F_{cu}	=	Characteristic concrete cube strength
h	=	Over all depth
I_{xx}	=	Moment of inertia
K	=	A constant (with appropriate subscripts)
L, l	=	The span
M	=	Bending moment due to ultimate load
M_c	=	Moment of resistance of the concrete in tension
M_o	=	Ultimate resistance moment
M_R	=	Reduced moment
m	=	Modular ratio
P_u	=	Ultimate load
p_u	=	Ultimate load per unit area

T	=	Tensile force in reinforcement
T_c	=	Tensile force in concrete
U_b	=	Perimeter of bamboo
V	=	Shear force due to ultimate loads
v	=	Shear stress
v_c	=	Ultimate shear stress in concrete
x	=	Neutral axis depth
y	=	Deflection
Z	=	Lever arm
α	=	A factor that takes the ratio between the direct compressive stress and the partial safety factor used for concrete
β	=	The ratio between the spans
γ_m	=	Partial safety against strength
ϕ	=	Curvature of the section
ε_c	=	Strain in concrete
ε_o	=	Strain in concrete at the intersection of the parabola with the rectangular part of the stress diagram.
ε_b	=	Strain in bamboo intension.

ABSTRACTS

The feasibility of using bamboo as an expedient material for reinforcing concrete structures as beams and slabs is studied. A rational analysis and design procedure based upon the limit state approach is presented. A large number of beams and slabs for various loading and support conditions were tested to assess the load carrying capacity. The serviceability requirement as crack width, long range and short range deflections were incorporated. Design charts are presented for a few cases and the experimental and theoretical results compared.

1. INTRODUCTION

1.1 General:

The role of a structural designer is to arrive at a structure that is safe and serviceable during its expected life time. The structure has to be designed in such a way that it meets the aesthetic and ecological requirements of the customer in particular and society in general. The primary purpose of structural design is force transmission through solid matter. Before embarking on the actual design of a structure, a designer should not only idealise the structure but also estimate the loads that are likely to act during its useful life. In design, the parameters that should be considered are geometry, material, load and behavioural. Depending upon the relative ratios of the sides, the structures are idealised as one-dimensional (beam, column etc) and two-dimensional (plate, shell, slab, etc.). Traditionally structures were designed by elastic theory and of late by plastic theory.

At the present time the trend is to design the structures by using both the elastic and the plastic theories. Statistical methods are used to analyse the variations in the loads on the structure and also the

strength parameters of materials used. The latest codes of practice around the globe employ the so called 'LIMIT STATE DESIGN' based upon the probability theory. Thus the purpose of design is to achieve an acceptable reliability. On other wards the probability of failure of a structure can be reduced to an acceptable low level as it is recognised that a structure can never be made completely safe.

1.2 Limit State Design:

The purpose of design is to ensure that all the criteria relevant to safety and serviceability are considered in the design process. Thus there are several criteria associated with limit states. A limit state is a design concept. Each criterion governs the performance of a structure or its unfitness for use. The number of limit states is equal to the number of failure modes of the structure. These are basically two types of failures namely collapse (ultimate) and functional (serviceability).

1.2.1 Terminology:

(a) Characteristic load: A characteristic load is a load that has a low probability of being exceeded during the life of a structure. The characteristic loads may be dead load, imposed load, wind load, seismic load or any other load that is likely to act on a structure.

(b) Partial factor of safety: It is a factor that allows for uncertainities in estimating loads and variations in strength of materials.

(c) Design loads: Design load is defined as the product of the characteristic load and the partial factor of safety.

(d) Characteristic strength: The characteristic strength is defined as the strength of the material below which not more than a few percent of test results fall.

(e) Design strength: The characteristic strength divided by the partial factor of safety of the material is known as the design strength.

1.2.2 Collapse Limit States:

The limit states of collapse to be considered are usually due to the structural failure of a structure or a part of it. The failure may be due to inadequate strength, buckling (elastic or plastic), overall instability, resonance, lightning, fire, durability, fatigue etc. A structure is proportioned in such a way that the resistance offered is not less than the appropriate value produced by the most probable unfavourable combination of design loads acting on the structure.

1.2.3 Serviceability Limit States:

A structure should be not only strong but should be functionally useful as well. A structure may be unserviceable because of excessive cracking, deflection, vibration etc.

1.3 Expedient Materials:

Limit state design is based on idealised stress-strain curves. At present, concrete is the most widely used building material. It is a heterogenous material possessing a high compressive strength and a low tensile strength. It has a limited specific modulus and little resistance to cracking. Because of its ability to redistribute the stresses concrete has been fully exploited as a construction material. The tension zones of concrete structures are reinforced by materials that are usually strong in tension. Traditionally steel has been used as a reinforcing material for quite some time. For the rural masses in the densely populated developing countries like India, steel and cement are not easily available . Hence it is imperative that scientists and technologists should come up, with substitute materials that are cheap and widely available. Even in developed countries (1970-6) specially during World War II, steel was not readily

available. Bamboo has been used as a building material from times immemorial. It is easily available in abundance, in tropical, subtropical and temperate zones. It is reasonably strong in tension with a limited ductility. It has a low modulus of elasticity comparable to that of concrete. Hence bamboo can be confidently used as a cheap reinforcing material for secondary or temporary concrete structures. Agro-based cementing materials such as rice husk cement is being manufactured and utilised as a substitute for traditional portland cement.

1.4 Historical Development:

As the saying goes 'Necessity is the mother of invention' revolutionary concepts are put forward and substitute materials put into use, when nations are under great stress of war or want. During the first world war timber was used as a substitute for steel reinforcement in concrete structures. Around the same time, bamboo was thought of as an expedient reinforcing material (Geymayer and Cox, 1970-6). During the second world war bamboo reinforced structures were constructed by the United States of America, Japan, Germany etc. In India, although bamboo has been in use for quite some time as a building material (construction of huts, bridges etc.), only now it is being used as an expedient material for reinforcement in low

cost temporary concrete structures. Bamboo reinforced structures are commonly found in far eastern parts of India. The Forest Research Institute (FRI) at Dehradun poineered in conducting preliminary experiments and constructed a few prototype structures as, a cluster of houses and bus shelters. However, no rational design procedures are given. In China and some South East Asian countries notably Thailand, bamboo has been exploited as a reinforcing material in the construction of roads, silos, houses, tennis and basket ball courts. Nagarajan (1976-5) has extensively reviewed the literature on the mechanical and physical properties of the bamboo. For the first time bamboo fibres were used as fibrous reinforcement in concrete for delaying the crack propagation and increasing the load capacity. Purushottam (1963-1), Masani (1951-2), Mehra (1951-3), Glenn (1950-4) also conducted some experiments on some aspect of bamboo or bamboo reinforced structures.

1.5 Scope of the Thesis:

In this thesis an attempt has been made to evolve rational design procedures for the design of bamboo reinforced concrete beams and slabs. The limit state concepts are used as the basis for design and analysis. A number of beams (simply supported and continuous) and slabs

(simply supported on four sides) were cast and tested for different loading conditions after the assessment of material properties of bamboo and concrete . In chapter one, the basic philosophy of limit state design along with the historical development of bamboo reinforced structures are presented. The mechanical and physical properties of the materials under consideration are presented in chapter two besides exposing the deficiencies of bamboo reinforcing material. The chapter three contains the experimental investigation of slabs and beams with different support conditions under various loads. The chapter four comprises of analysis of beams and slabs, and a comparison of theoretical and experimental results. Design charts are also prepared. Finally the last chapter encompasses the discussion of results, conclusions drawn and the suggestions for further study.

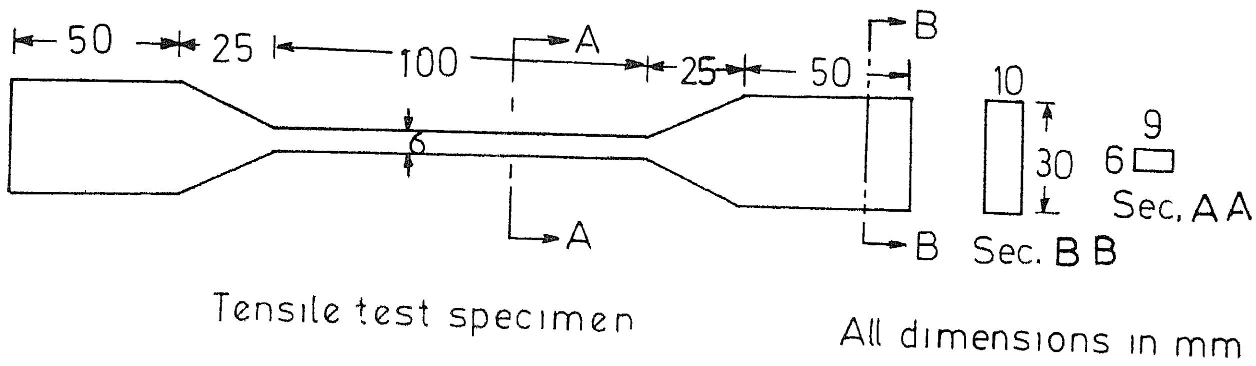


FIG. 2·1

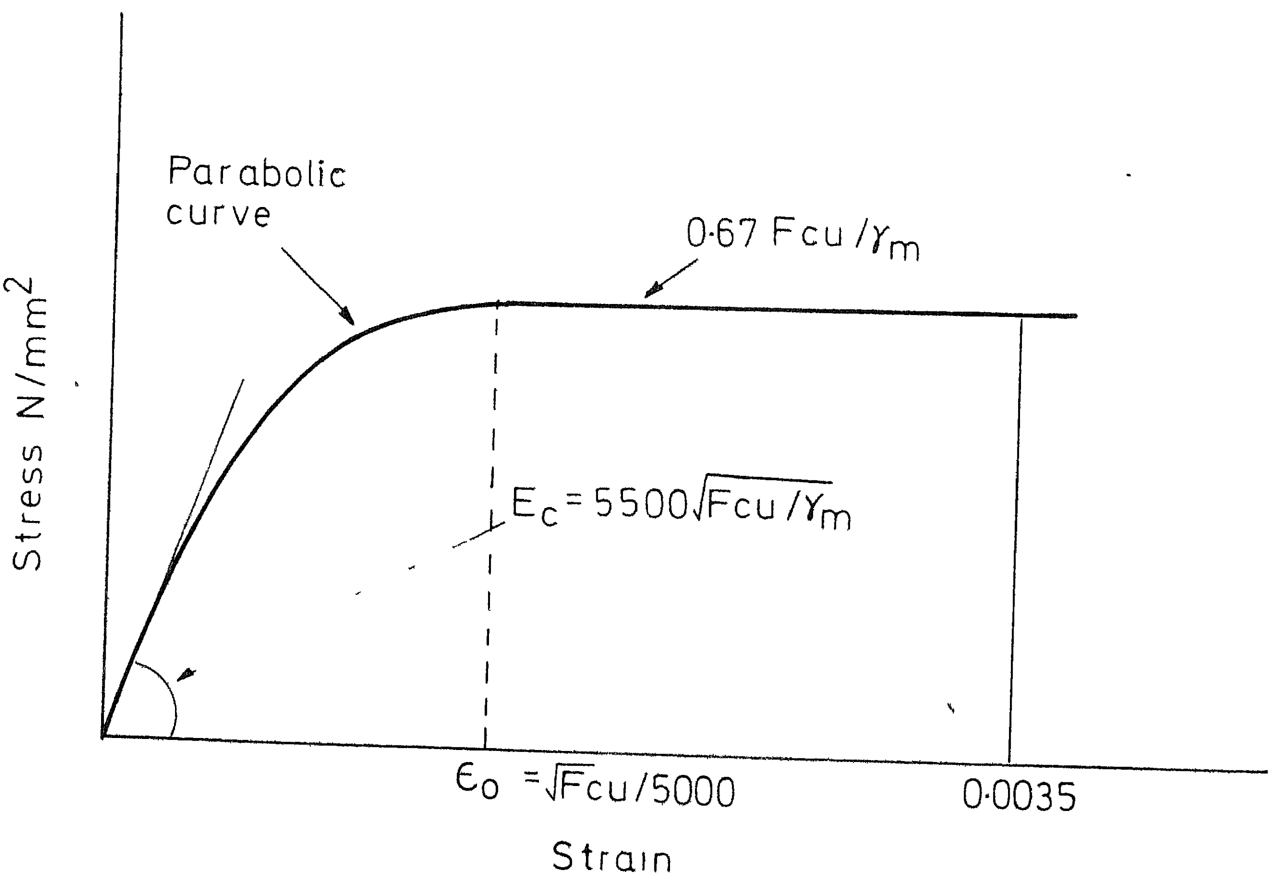
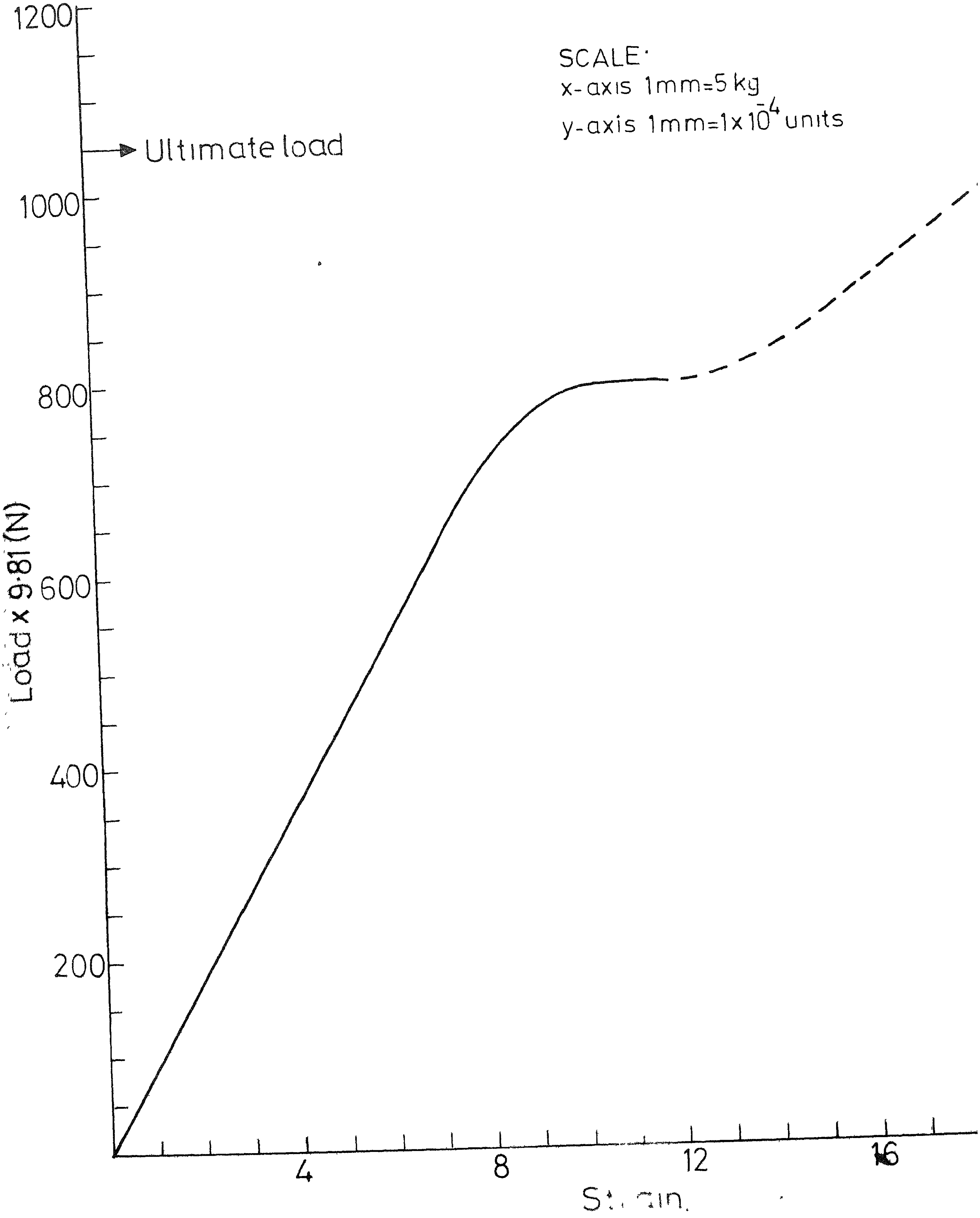


FIG. 2·5 SHORT TERM DESIGN STRESS-STRAIN CURVE FOR CONCRETE



FIG·2·2 LOAD STRAIN CURVE

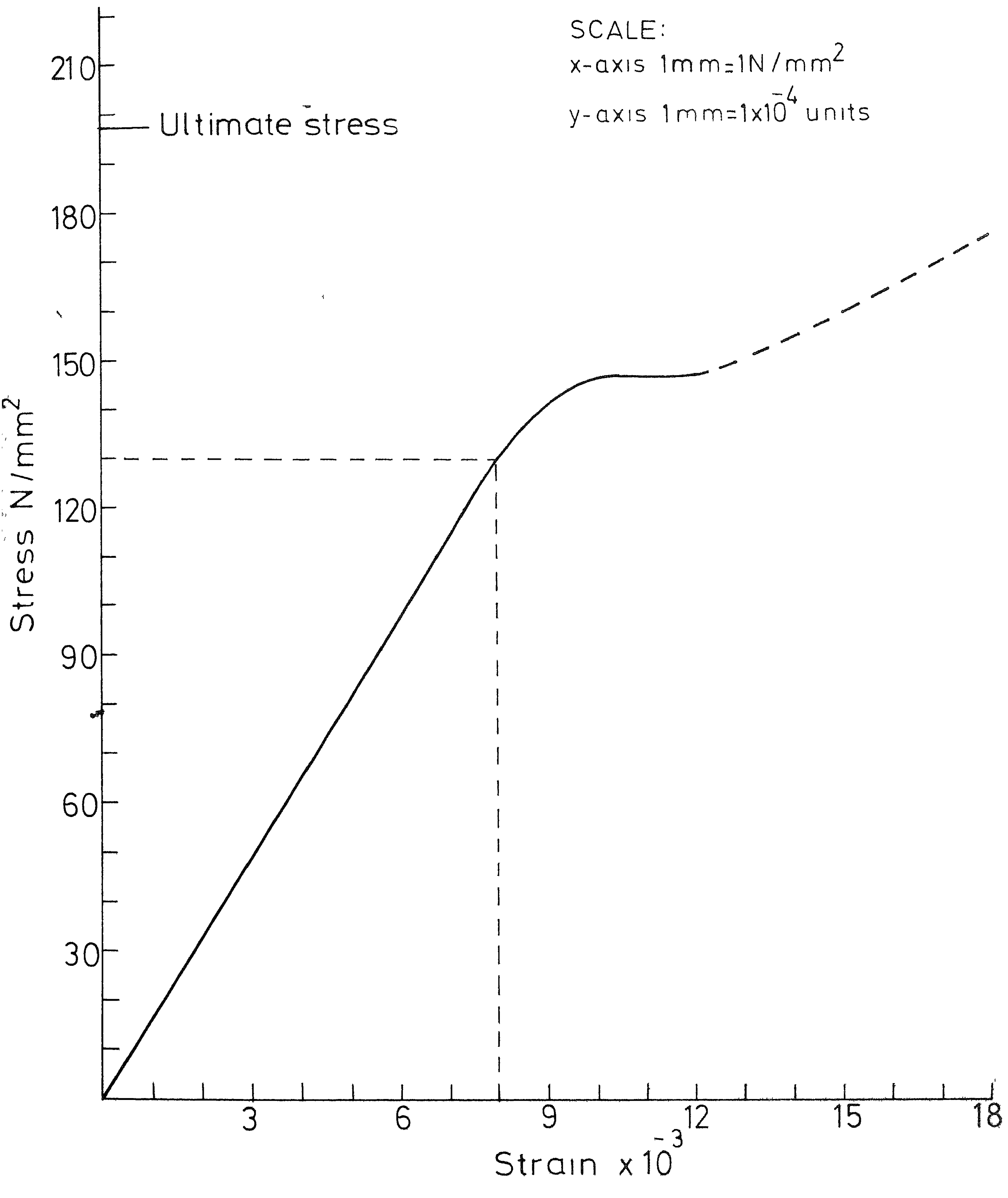


FIG. 2·3 STRESS-STRAIN CURVE

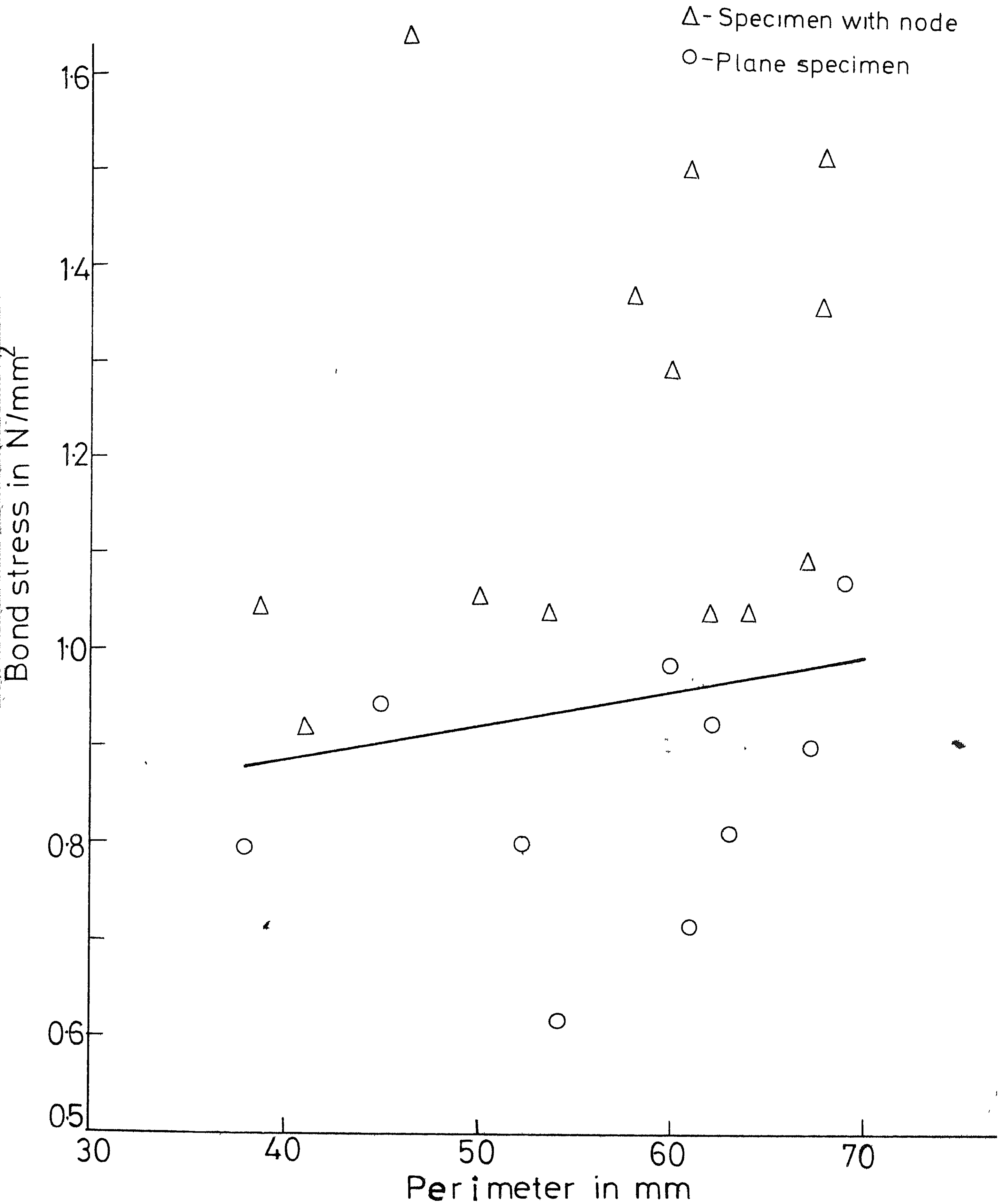


FIG. 2·4 BOND STRESS VS PERIMETER

2. MATERIAL PROPERTIES

2.1 General:

Bamboo reinforced concrete is a concrete embedded with bamboos. In this chapter an attempt has been made to review the properties of materials under consideration, viz., bamboo and concrete. The properties of concrete are very well documented in standard text books as Macginley (1978-7), Troxel and Davis (1956-10) etc. The mechanical and physical properties of bamboo are scantly available in literature.

2.2 Bamboo:

Bamboo is a perennial grass that grows in almost all climatic conditions. There are over 500 species of bamboo available in nature. Flowers and fruits are produced at intervals of 30 to 50 years or even longer. The identification of the plant is based on the characteristics of its fruits and flowers. The growth is very rapid and at times it may be as much as 600 mm in a day. The usual height of bamboos ranges from 15 to 20 metres. The basal diameter may vary from 200 to 300 mm. The diameter of the culms gradually decreases from basal to the distal end. As it is an organic material the properties vary very widely depending upon the species and the climatic conditions.

The principal problems associated with bamboo reinforcement are volume changes due to moisture migration and bond strength. The coefficient of thermal expansion is different in diagonal and longitudinal directions. A bamboo culm is divided into a series of nodes. The inter nodal distance varies from 200 to 500 mm. Because of the presence of the nodes the strength properties of the bamboo differ from one portion of the bamboo to the other. A designer should have an idea about the following properties, viz., tensile strength, compressive strength, modulus of elasticity, flexural strength, bond strength, thermal properties, creep, changes in moisture content, decay etc. The afore mentioned properties were investigated by various workers as Purushottam (1963-1), Masani (1951-2), Mehra (1951-3), Glenn (1950-4), Nagarajan (1976-5), Geymayer and Cox (1970-6) etc. and listed below.

2.2.1 Tensile Strength:

The bamboos may fail in tension, basically, in two modes. The failure may be either at the node or in between the nodes. The tensile strength of the outer layers is observed to be more than the inner layers of the bamboo culm. The range of values recorded in the literature are 210 to 250 N/mm^2 for nodal and internodal failure

planes, 150 to 300 N/mm^2 for different layers of bamboo culm and 100 to 300 N/mm^2 for various types of bamboo.

2.2.2 Compressive Strength:

The compressive strength of bamboo depends upon the slenderness ratio of the specimen and the diameter to the thickness ratio of the bamboo culm. The compressive strength is around 25 percent of the tensile strength.

2.2.3 Modulus of Elasticity:

In the case of bamboo, the modulus of elasticity recorded in a tension test differs from that of a compression test, the former being more than the latter by 15 percent. The range of tensile moduli of elasticity is 1.0×10^4 to 2×10^4 N/mm^2.

2.2.4 Flexural Strength:

Although the flexural strength of the bamboo split culm (stile) depends upon the orientation of the specimen (whether the exterior side of the bamboo is up or down), the flexural stresses recorded, when the exterior side is up, are in the range of 130 to 150 N/mm^2. The values are slightly lower for specimens tested with the exterior side down.

2.2.5 Creep of Bamboo:

Not much of information about the creep of seasoned bamboo specimens is available in the literature. When certain species of bamboo are loaded under direct tension (The stress range being 20 to 60 N/mm^2) for one year, elongation is found to be about 40 percent of the instantaneous values.

2.2.6 Moisture Absorption:

The greatest draw back of using bamboo as a reinforcing material is its volume instability. The changes in volume across the fibre are far more than those along the fibre. The bamboo absorbs moisture 200 to 300 percent of its weight.

2.2.7 Decay:

The bamboo decays mainly because of fungus, soft rot, insect attack etc.

2.3 Strength Parameters:

The following tests were conducted in structural engineering laboratory of Indian Institute of Technology, Kanpur.

2.3.1 Tensile Test:

A number o f split culms (15) were cut into specimens

as shown in Fig. 2.1. The specimens were tested using 200 tonnes Tinius Olsen Universal Testing Machine. The tensile stress values recorded fall in the range of 180 to 200 N/mm^2. The load versus deformation curve for a typical specimen is shown in Fig. 2.2. Two demec points were afixed on the specimen at a centre to centre distance of 79 mm for measuring the elongation. The load-~~deformation~~ strain curve shown in Fig. 2.2 is recorded directly on the testing machine with the aid of a 50 mm gauge length automatic extensometer. The corresponding stress-strain curve is shown in Fig. 2.3.

Characteristic strength	-	130 N/mm^2
Yield strain	-	0.008
Tensile modulus	-	1.625×10^4 N/mm^2

2.3.2 Bond Test:

Twentyfour split bamboo culms of different sizes (different cross section) 'with and without nodes' were prepared. These stiles were embedded along the axis of the concrete cylinders (150 Ø x 300 mm). The length of embedment is maintained as 300 mm in all the specimens. The concrete mix is M15. The pull-out tests were carried out on the Universal Testing Machine and the results were tabulated in Table 2.1. The results are plotted on a

graph (perimeter versus average bond stress) shown in Fig. 2.4. The bond stress values are high when nodes were embedded in the concrete. A straight line was fitted (using the least square method) discarding the off-shot points. It can be readily observed that the bond stress is directly proportional to the perimeter.

2.4 Concrete:

The properties of concrete are derived from the short term design stress-strain curve for concrete (1978-7) as shown in Fig. 2.5.

For the mix M15,

Ultimate cube strength of concrete at 28 days (F_{cu})

$$= 15 \text{ N/mm}^2$$

Ultimate strain $= 0.0035$

Youngs modulus of concrete $= 5.5\sqrt{\frac{F_{cu}}{r_m}} = 1.739 \times 10^4$ N/mm^2 (2.1)

(where r_m is partial safety factor for concrete and is equal to 1.5).

The strain at which concrete started yielding

$$= \varepsilon_o = \sqrt{F_{cu}}/5000 = 0.0007746. \qquad (2.2)$$

The maximum design stress $= \sigma_{cu} = \frac{0.67\ F_{cu}}{r_m} = 0.45\ F_{cu}$ (2.3)

where, the factor 0.67 takes into account the ratio of the characteristic cube strength to the bending strength in a flexural member.

TABLE 2.1 : BOND TEST RESULTS

S.No.	Perimeter (mm)	Surface area (mm^2)	With or without node	Load in (N)	Average bond stress x.1(N/mm^2)	Mode of failure
1	46	13800	Node	12850	9.15	Slip
2	50	15000	Node	14125	10.55	''
3	45	13500	-	8340	9.40	''
4	54	16200	-	26685	6.20	''
5	46	13800	Node	14815	16.40	''
6	60	18000	Node	23250	12.95	''
7	68	20400	Node	31880	15.65	''
8	41	12300	Node	11280	9.20	''
9	38	11400	-	8945	7.85	''
10	69	20700	-	21780	10.70	''
11	52	15600	-	14815	8.00	''
12	62	18600	-	19425	9.50	''
13	38	11400	Node	9125	10.45	''
14	64	19200	-	25115	10.35	''
15	58	17400	Node	16580	13.05	''
16	62	18600	-	13340	9.50	''
17	61	18300	-	18980	7.15	''
18	67	20100	Node	22070	11.00	''
19	62	18600	-	19230	10.35	''
20	60	18000	-	17705	9.85	''
21	53	15900	Node	16580	10.40	''
22	68	20400	Node	27660	13.65	''
23	67	20100	-	18130	9.00	''
24	63	18900	-	15300	8.10	''
25	61	18300	Node	27660	15.10	''

2.5 Modulus of Elasticity of Composite Material (E_{cb}):

The bounds on the modulus of elasticity of a composite material are given by the law of mixtures.

Upper ~~Lower~~ bound: $E_{cb} = E_m V_m + E_F V_F$ (2.4)

Lower ~~Upper~~ bound: $1/E_{cb} = (V_m/E_m) + (V_F/E_F)$ (2.5)

where V is the volume fraction and the subscripts 'm' and 'F' stand for matrix and filler respectively. In this thesis the matrix is concrete and filler is bamboo.

E_{cb} varies from structure to structure depending on the percentage of reinforcement provided.

A Typical calculation for E_{cb} is shown below.

Data:

Area of reinforcement $A_b = 300\ mm^2$

Area of concrete $A_c = 19700\ mm^2$

Characteristic strength of concrete $F_{cu} = 15\ N/mm^2$

Partial safety factor for concrete $r_m = 1.50$

Bamboo is through out the span. The properties of concrete are derived from Fig. 2.5.

Using equation (2.1) E_c is obtained as

$$E_c = 5.5 \sqrt{\frac{F_{cu}}{r_m}} = 5.5 \sqrt{\frac{15}{1.5}} = 17.39\ KN/mm^2$$

E_b is read from Fig. 2.3 as

$$E_b = 16.25 \text{ KN/mm}^2$$

Using equations (2.4) and (2.5) the upper and lower bounds for E_{cb} are calculated.

$$E_{cb} \text{ (lower bound)} = 17.39 \times 0.985 + 16.25 \times 0.015$$

$$= 17.3729 \text{ KN/mm}^2.$$

$$E_{cb}\text{(upper bound)} = \frac{E_m \; E_F}{E_F \; V_m + E_m V_F}$$

$$= \frac{17.39 \times 16.25}{16.00 + 0.26} \text{ KN/mm}^2$$

$$= 17.379 \text{ KN/mm}^2$$

As the bounds are very close E_{cb} is taken as

$$E_{cb} = 17.375 \text{ KN/mm}^2.$$

3. EXPERIMENTS ON BEAMS AND SLABS

3.1 Aim:

The aim of this thesis is to propose a rational design procedure for bamboo-reinforced beams and slabs. With this in view a detailed experimental program was planned to study the behaviour of bamboo-reinforced beams and slabs at different load levels. In all eight simply-supported beams under third-point loads, four continuous beams subjected to mid-span concentrated loads and seven simply-supported slabs under uniform load were tested under static loads. Three simply-supported beams (third point loads) were also tested dynamic loads (single stroke pulsating unit).

3.2 Casting of Specimens:

3.2.1 Concrete mix:

All the specimens were cast with a concrete mix of proportions 1:2:4 by weight. The cement used was either the ordinary portland cement or portland Pozzolana cement. The sand used was from Yamuna river near Kalpi, Uttar Pradesh. The coarse aggregate was hard granite stone chips passing through 12 mm mesh. The water-cement ratio ranged from 0.5 to 0.65 by weight. Whenever a test specimen was cast,

six standard cubes (150 x 150 x 150 mm) were also cast. These cubes were tested in the 130 tonnes compression testing machine available in the Structural laboratory on the day of the structural test. The concrete was mixed in a power driven mixer. The crushing strength values are shown in Table 3.1. All the cubes were cured in a water tank till the day of the test.

3.2.2 Beam and slab elements:

Two series of beams (eleven of 100 x 200 x 2000mm and four of 100 x 200 x 3050 mm) and a single series of slabs (seven of 1500 x 1500 x 70 mm) were cast and cured under wet gunny bags for 28 days. The reinforcement details are shown in Fig. 3.1 to Fig. 3.3. When made from slow-setting cement, reinforcements were soaked for a period of two days or so, otherwise , cracks parallel to the bamboo reinforcement appeared on the face of the beams and slabs.

3.3 Experimental Procedure and Results:

3.3.1 Simply supported beams:

Singly-reinforced rectangular beams were mounted on two supports, simulating a hinged support at one end and roller support at the other. The centre-to-centre distance between the supports was 1800 mm. Third-point

loading was done through two hydraulic jacks of four tonnes capacity each, suspended from a reaction girder which inturn was bolted to the strong floor (test bed). Five dial gauges (50mm travel distance and least count of 0.01 mm) are positioned underneath the beam at equal intervals to fecilitate the measurement of deflections. The general arrangement for complete test is shown in plate 3.1 and also in Fig. 3.4. The load is gradually increased in increments of 100 kg. till failure. The deflections were recorded at all stages of the loading. All the beams were tested till uncontained plastic flow was noticed. Width of a crack was measured using filler gauges.

The load versus maximum deflection curves, the final crack patterns and the deflected shape at various loading stages are shown in Fig. 3.5 (a and b) plate 3.2 (a through d) and Fig. 3.6 (a through h) . The results are also presented in Table 3.1.

For the same cross-section of the beams when the amount of reinforcement was varied from 280 mm^2 to 440 mm^2 the span-deflection ratios were found to fall in the range of 2250 to 1800. As can be observed from the load-deflection curves shown in Fig. 3.5(a and b) the deflections are fairly small prior to the appearance of

the first crack. The deflection increased at a faster rate at later stages. At failure the cracks invariably appeared at the interface between the convex side of the stile (smooth side and the concrete). The orientation of the bamboo influences the rigidity of the beams. This can be readily seen from the graphs (Fig. 3.5(a and b)) wherein the slope of the load deflection curve is steeper for those beams (B_1, B_2, B_3) in which the convex side of the bamboo stile is nearer to the tension face. The strength of the concrete may also have a marginal effect, as the Young's modulus is proportional to the strength of the concrete. In beams B_3 and B_8 the reinforcement failed at the nodal points. The maximum crack width was found to be 0.03mm for a load of 5450 N.

3.3.2 Continuous beams:

Four specimens (100 x 200 x 3050 mm) were tested as two-span continuous beams (three unequal spans of 1600 and 1300 mm and one equal span of 1450 mm). The loading arrangement, the support conditions and the locations of the dial gauges are shown in Fig. 3.7 and in plate 3.3. Mid-span concentrated loads were applied as in the case of simply supported beams described earlier. The load was gradually increased in increments of 100 kg.

till failure. The test results are shown in Table 3.2. The deflections were recorded at all stages of the loading. All the beams were tested till uncontained plastic flow was noticed.

The load versus maximum deflection curves, the final crack patterns in the beams and the deflected shape at various loading stages are shown in Fig. 3.8, plate 3.3 and Fig. 3.9 (a through d). In the case of unequal spans (B_{11}, B_{22}, B_{33}) as expected, the longer span collapsed when the loads were kept equal and increased gradually. The negative and positive reinforcements were not equal, hence the inequality of moment capacities.

As expected the slope of the load-deflection curves (Fig. 3.8) is found to be steeper than those for simply supported beams. Hence the first crack appeared at a load that is almost thrice that of the simply supported case. The negative moment capacity of the beam was made smaller than that of the positive moment capacity so that the positive and negative hinges formed simultaneously. Even in the case of equal spans (B_{44}) the left span failed prior to the right one. A node was found in the reinforcement exactly at the failure section.

3.3.3 Slabs:

Seven slabs (1500 x 1500 x 70 mm) simply-supported

on all sides subjected to a uniformly distributed load were tested to distruction. The slabs were made to rest on rollers which inturn were supported by a steel frame (the modulus of rigidity of the frame was far more than that of the slabs) resting on four brick pillars. The load was applied directly by sand encased in stiffened plywood boxes. Five dial gauges were positioned to record the deflection of slab at various load levels. The complete arrangement is shown in plate 3.4. The load was gradually applied in increments of 4900 N. The deflections were recorded for all loading stages. The load versus maximum deflection curves for various slabs are shown in Fig. 3.10 (a and b). No negative reinforcement was provided even in the corners of the slabs. The loading arrangement was such that the corners were always held down by the box. The weight of the box was directly transferred to the supports.

The details of the experimental results and the final crack patterns are shown in Table 3.3 and in plate 3.5 (a through d) respectively.

Micro-cracks parallel to the direction of the reinforcement appeared when the load level was 30 to 40 KN. Almost all the slabs exhibited the same mode of failure.

Soon after the first crack appeared, plastic flow (increase in strain for zero stress **rate**) was noticed in slabs (S_1 and S_2) with widely spaced reinforcement. This can be noticed in Fig. 3.10 (a). **All the slabs** collapsed totally at 1.5 to 2.0 times the first crack loads. The order in which the cracks formed in almost all the slabs is shown in Fig.3.11.

3.3.4 Beam subjected to pulsating load:

Three beams (100 x 200 x 2000 mm) simply-supported at both ends were subjected to pulsating loads at third-points applied through a jack of 4 tonnes capacity using RIEHLE Sc 10 pulsator. Four strain gauges (gauge factor 2.0) were mounted on the surface of the beam (one on the top and three on a side face) so that the strains could be recorded as the loading was gradually increased. The location of the strain gauges is shown in Fig. 3.12.

The load-deflection curves are shown in Fig.3.13 (a and b) (PB_2 and PB_3). For beam PB_3 the load-strain curve (compression) is shown in Fig. 3.14. The function of the strain gauges is **impaired** , the moment a visible crack passes through it.

The upper load was maintained at 40 percent of the ultimate load of the structure and the lower load at 10 percent.

The maximum frequency at which pulsation could be applied was found to be 500 cycles per minute. The experiments are preliminary in nature.

TABLE 3.1: SIMPLY-SUPPORTED BEAMS (TEST RESULTS)

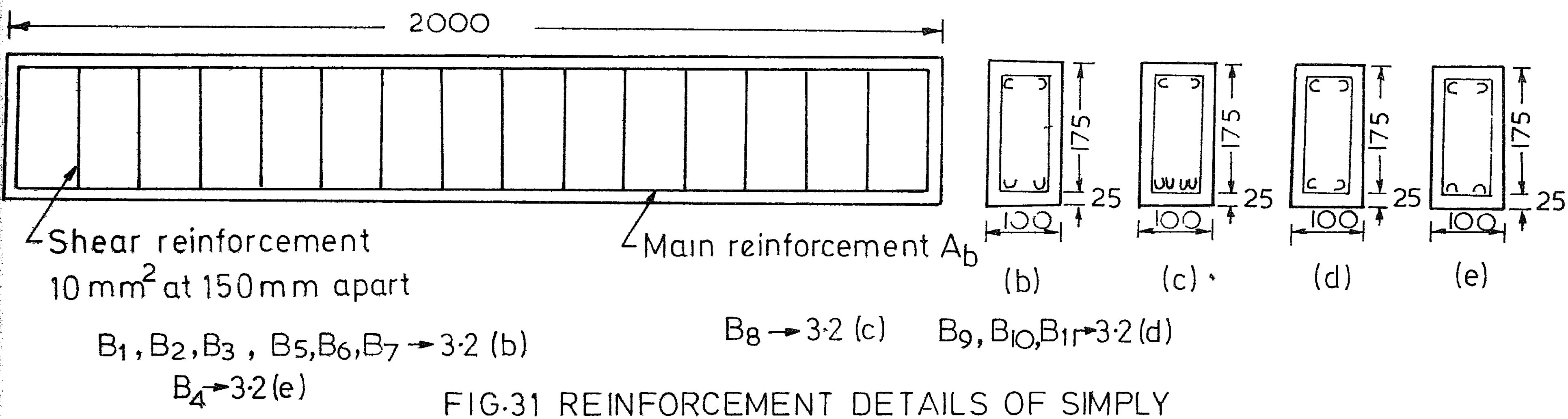
Specimen Number	Orientation of Stile (Bamboo)	Number of Stiles	Area of Reinforcement (A_b) (mm^2)	Age at Test (days)	Cube Strength (N/mm^2)	First Crack Load (KN)	Ultimate load (KN)	Remarks
B_1	Concave Face up	2	332	33	24	1.85	11.75	Bond failure
B_2	Concave Face up	2	344	30	21	2.765	12.25	Bond failure
B_3	Concave Face up	2	278	28	30	3.50	11.50	Bond failure
B_4	Concave Face Down	2	340	27	23	3.60	12.12	Bond failure
B_5	Concave Face up (Bundle)	6	280	28	21	2.305	11.70	Secondary bond failure
B_6	Concave Face Inward	2	350	28	17	2.765	11.25	Bond failure
B_7	Concave Face Inward (Bundle)	4	440	28	17	1.85	11.75	Bond failure
B_8	Concave Face Inward	2	384	28	19	2.765	11.55	Bond failure

TABLE 3.2 : TWO-SPAN CONTINUOUS BEAMS (TEST RESULTS)

Speci-men Number	Equal or Unequal Spans	Number of Stiles	Area of Reinforcement (A_b)		Cube Strength	First Crack Load		Ulti-mate Load (KN)	Remarks
			Mid-span (mm^2)	Mid-support (mm^2)	(N/mm^2)	Longer Span (KN)	Mid-Span (KN)		
B_{11}	Unequal	2	280	172	18	9.20	8.30	17.85	Longer span collapsed
B_{22}	Unequal	2	260	169	16	7.30	6.45	17.25	-do-
B_{33}	Unequal	2	275	156	16	7.30	6.45	17.40	-do-
B_{44}	Equal	2	309	147	15	7.30	6.45	21.65	Left span collapsed

TABLE 3.3: SIMPLY-SUPPORTED SLABS (TEST RESULTS)

Specimen Number	Number of Stiles	Area of Reinforcement (A_b) (mm^2)		Cube Strength (N/mm^2)	Age at Test (Days)	First Crack Load(KN)	Ultimate Load (KN)
S_1	5	640	660	24	48	29.50	78.50
S_2	5	950	960	21	35	44.00	88.00
S_3	8	971	980	19	28	44.00	88.00
S_4	8	1000	1010	17	28	44.00	83.50
S_5	8	970	986	15	28	29.50	83.50
S_6	8	502	521	15	28	39.00	54.00
S_7	8	592	612	17	28	39.00	63.50



FIG·31 REINFORCEMENT DETAILS OF SIMPLY SUPPORTED BEAM

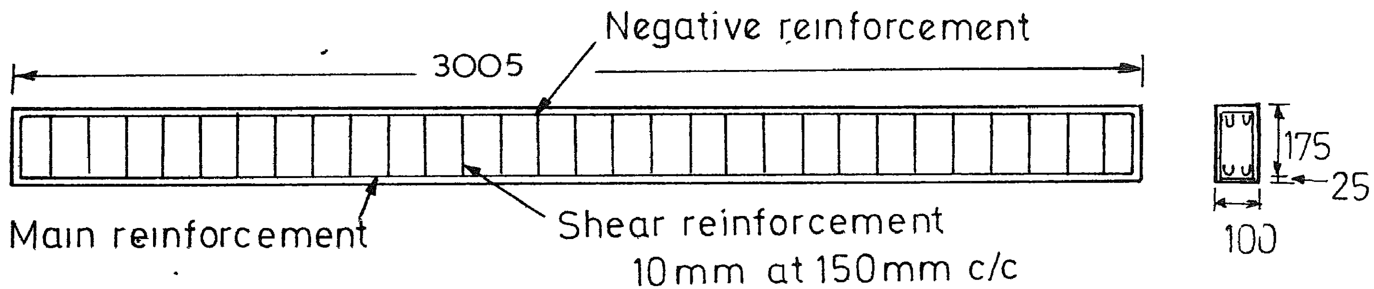


FIG 3·2 REINFORCEMENT DETAILS OF CONTINUOUS BEAM

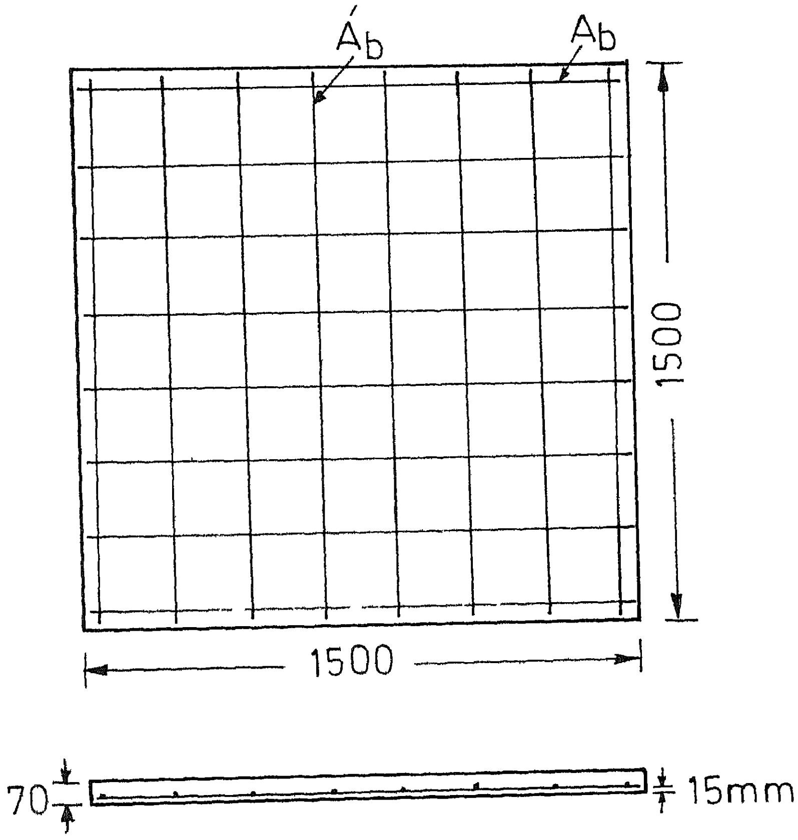


Fig.3·3 Reinforcement details of simply supported slabs

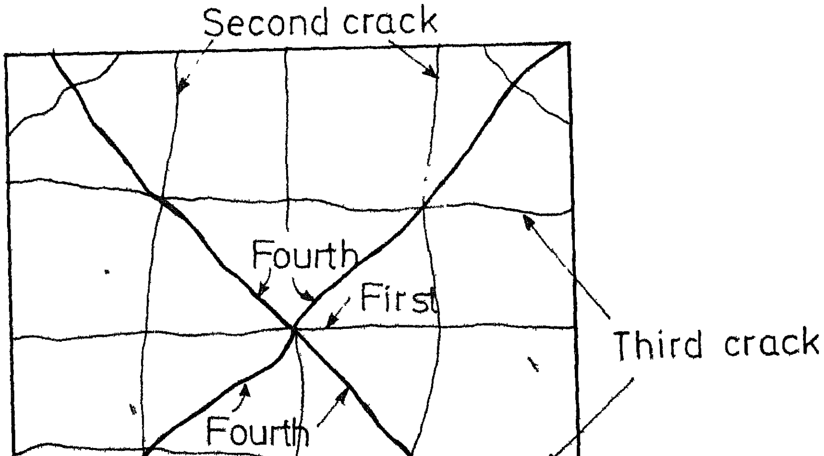


Fig.3·11 Crack pattern in slabs

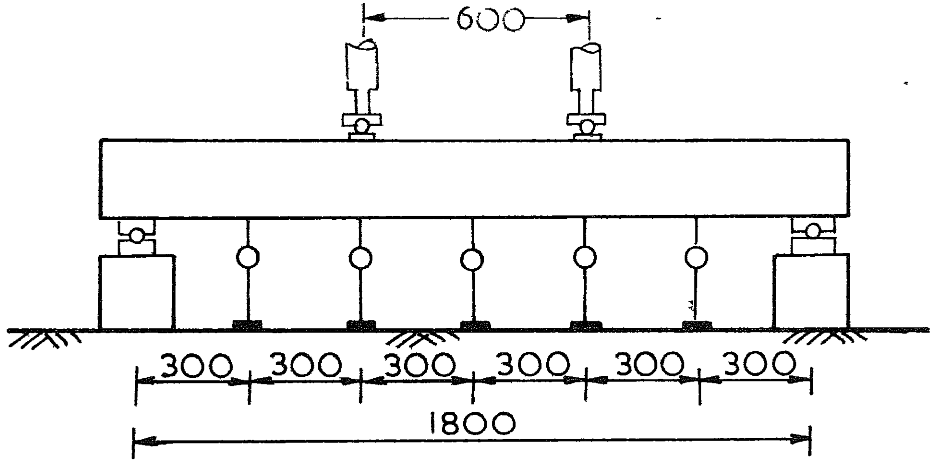


FIG.3.4 SIMPLY SUPPORTED BEAM (TEST SET UP)

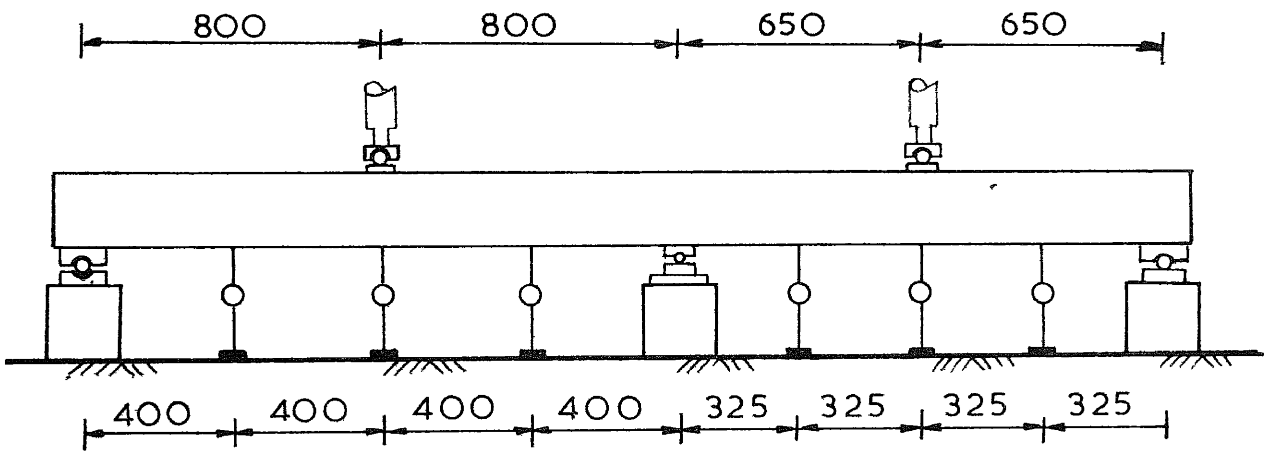


FIG.3.7 TWO SPAN CONTINUOUS BEAM (TEST SET UP)

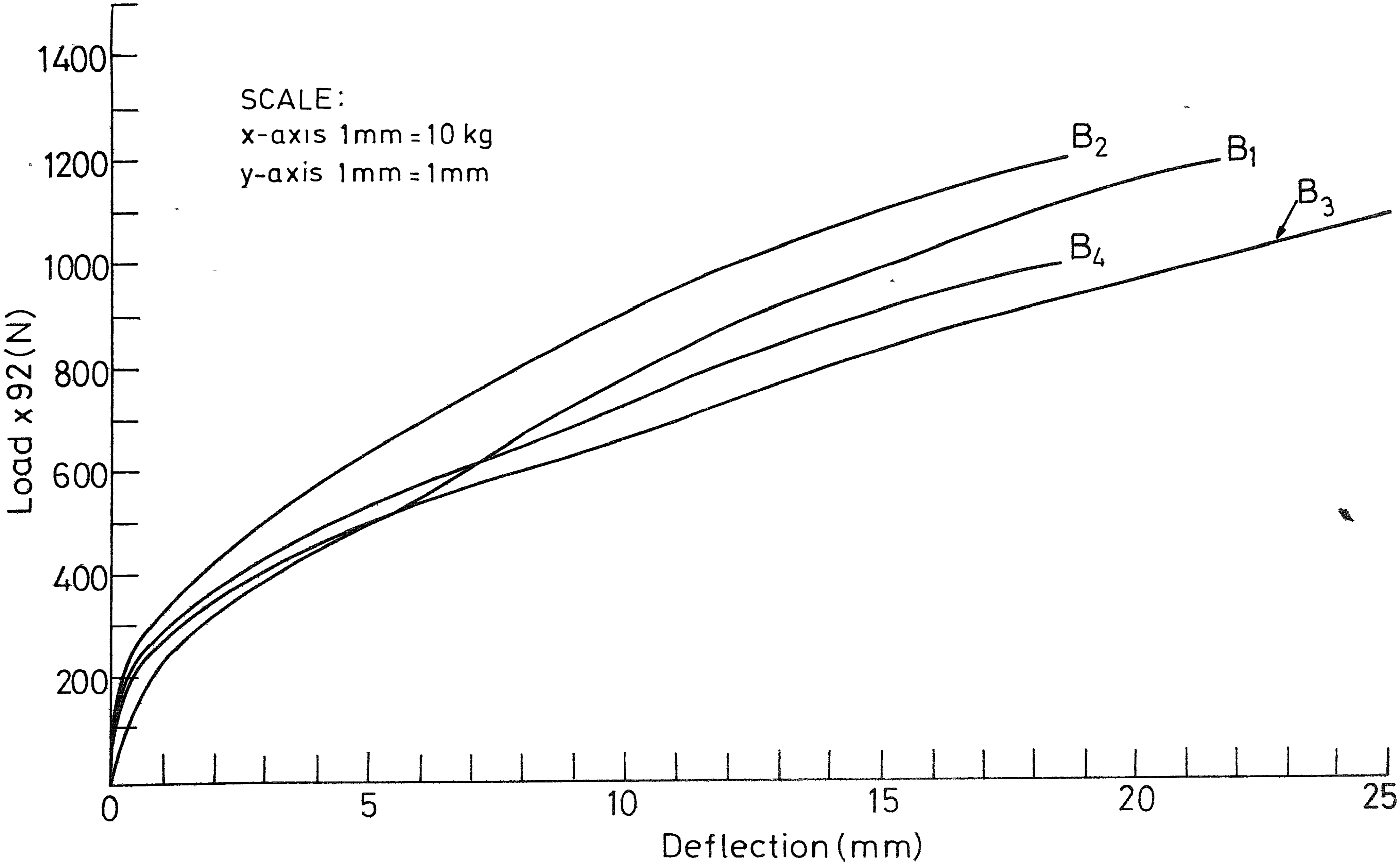


FIG. 3·5 (a) LOAD-DEFLECTION CURVE

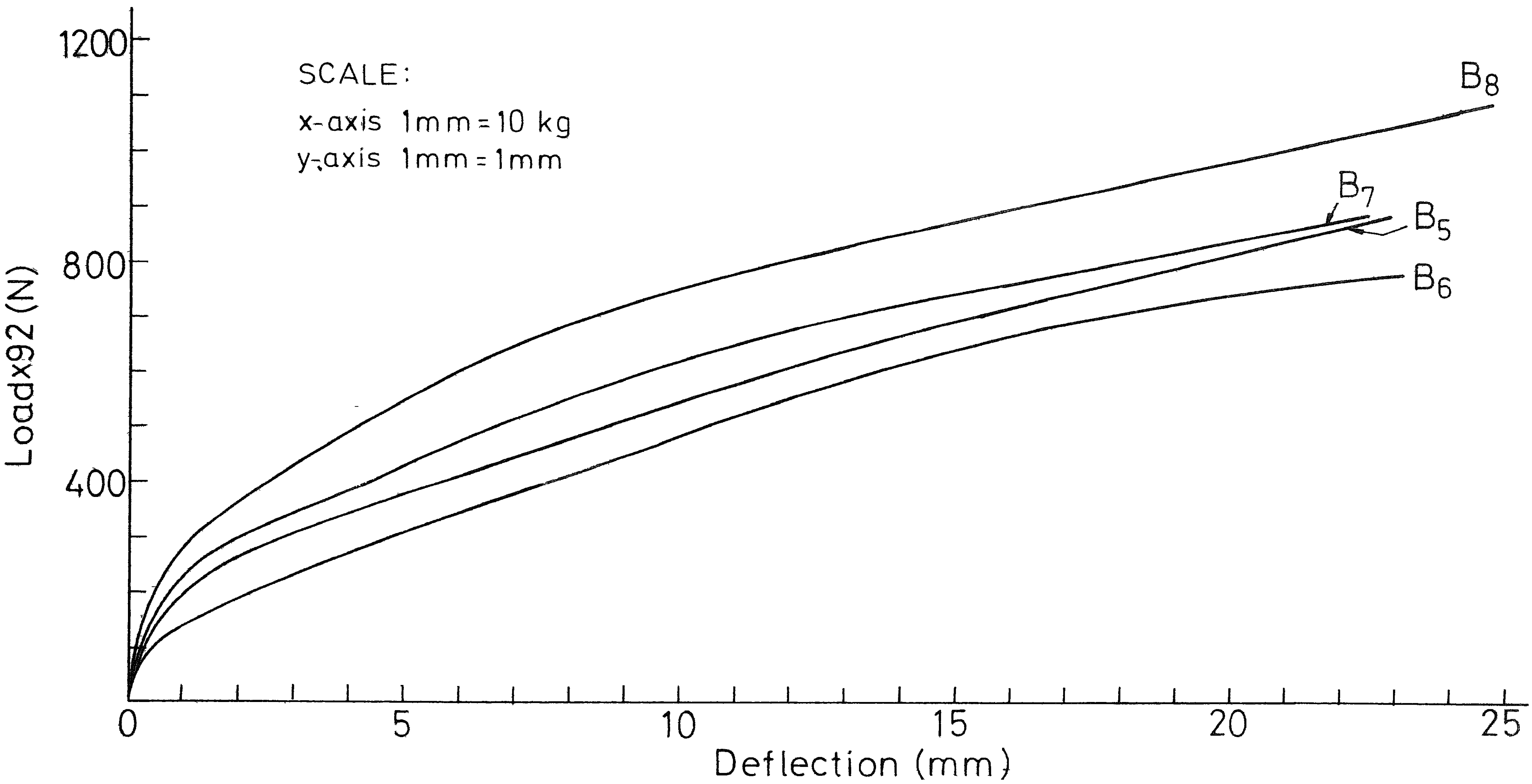
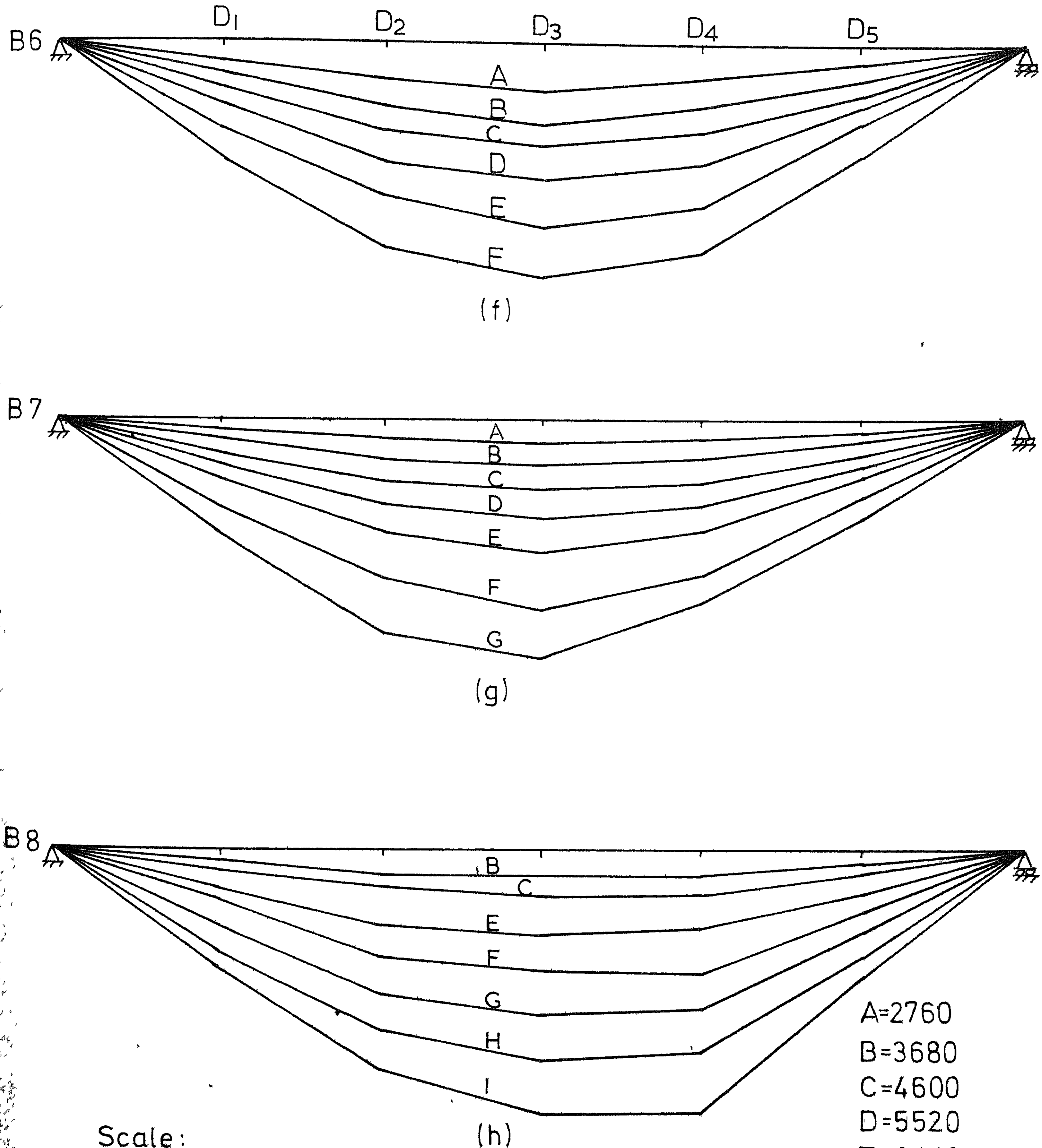


FIG. 3·5(b) LOAD-DEFLECTION CURVE



Scale:
x-axis 1mm = 10 mm
y-axis 1mm = 1/2 mm

A=2760
B=3680
C=4600
D=5520
E=6440
F=7360
G=8280
H=9200
I = 10120

FIG.3.6 DEFLECTION PATTERN

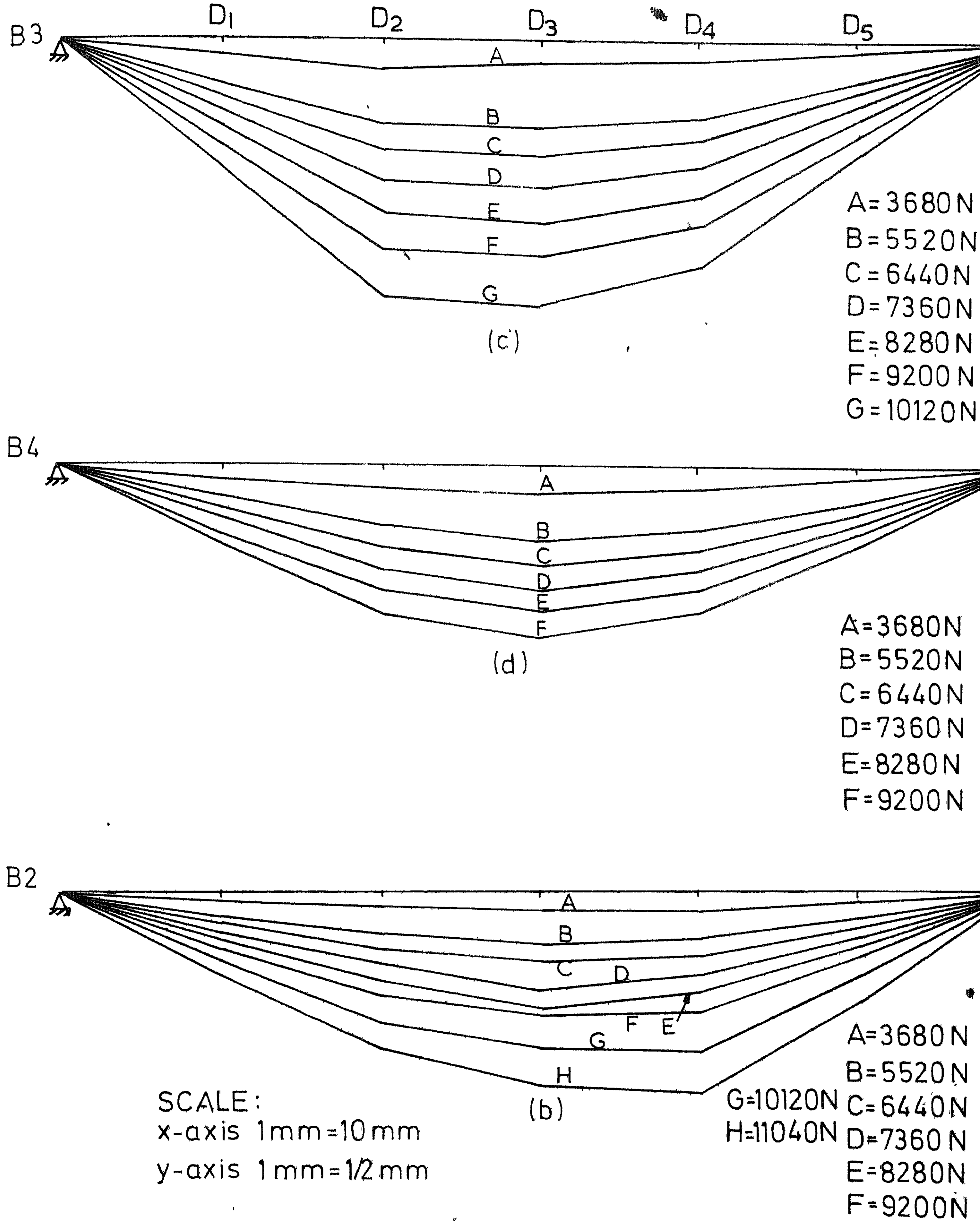


FIG.3.6 DEFLECTION PATTERN

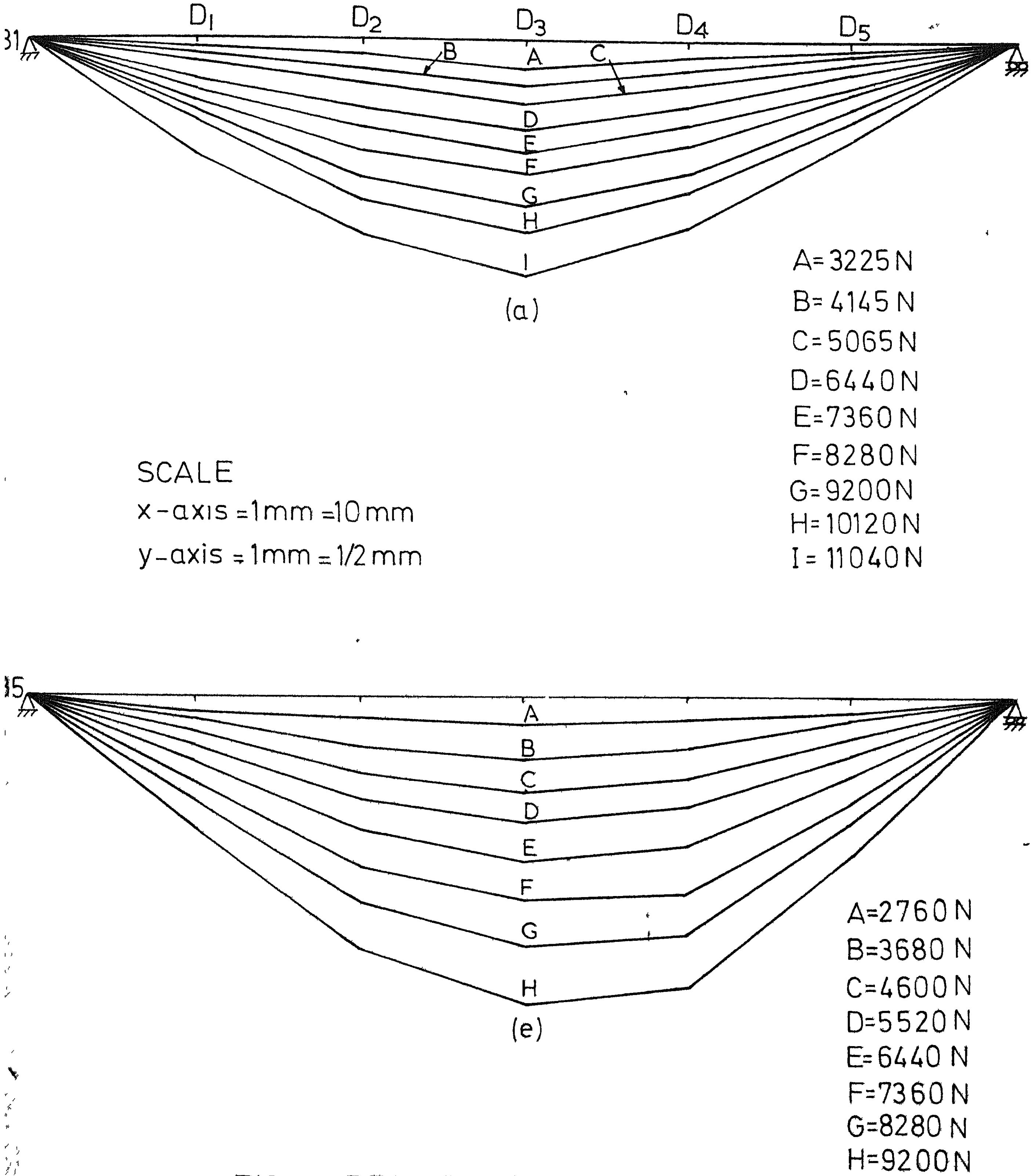


FIG.3.6 DEFLECTION PATTERN

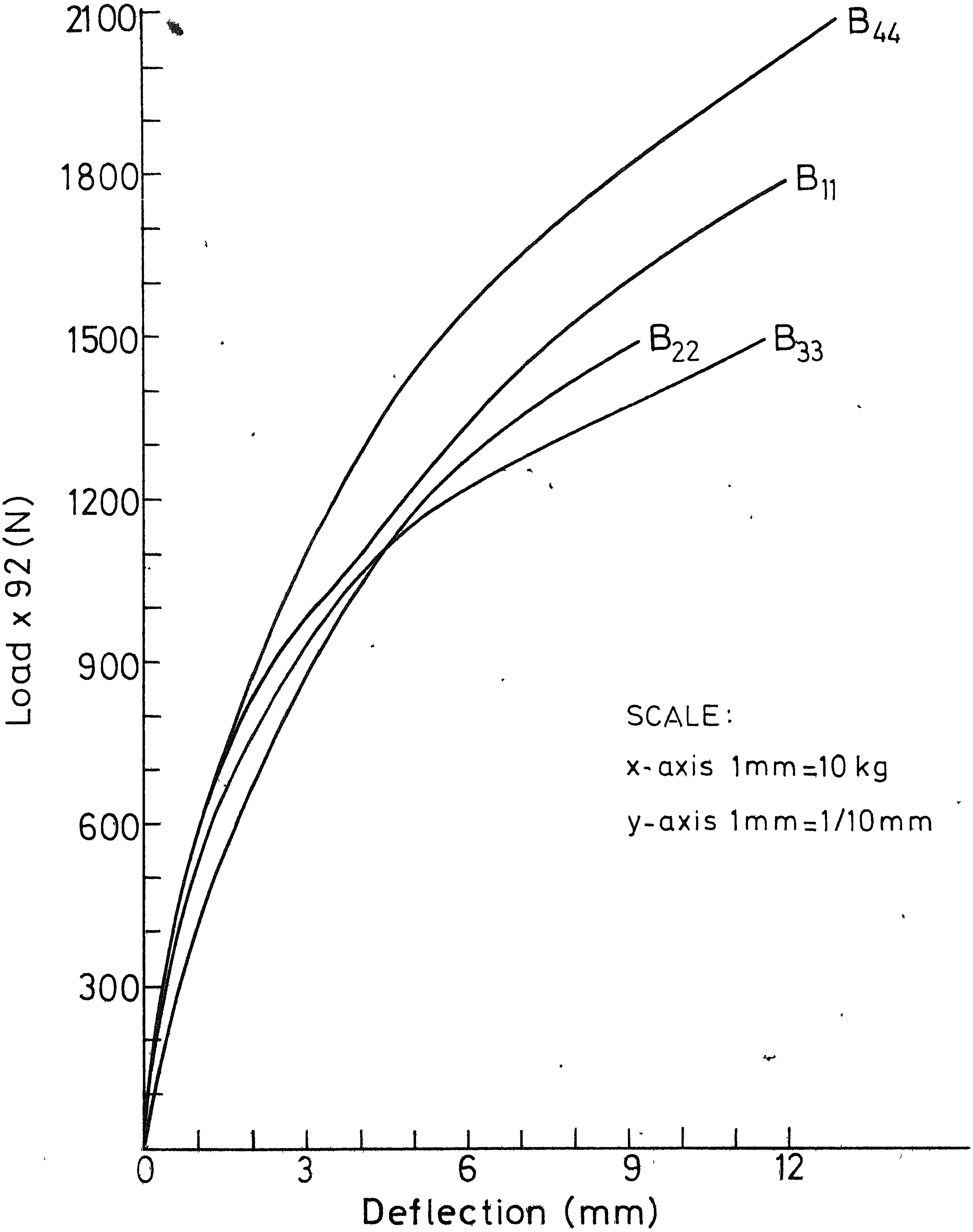


FIG.3·8 LOAD-DEFLECTION CURVE (For failure spar

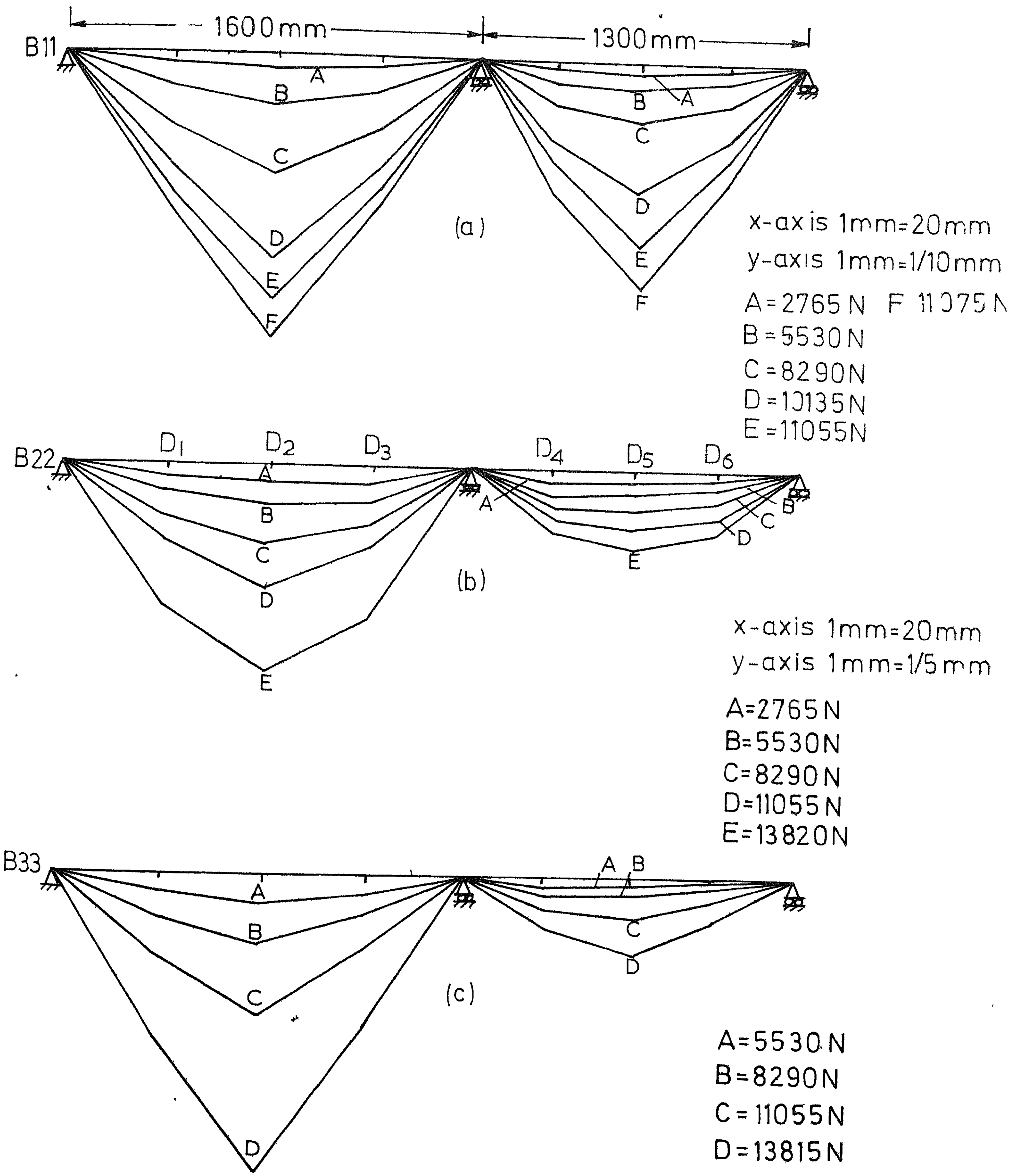
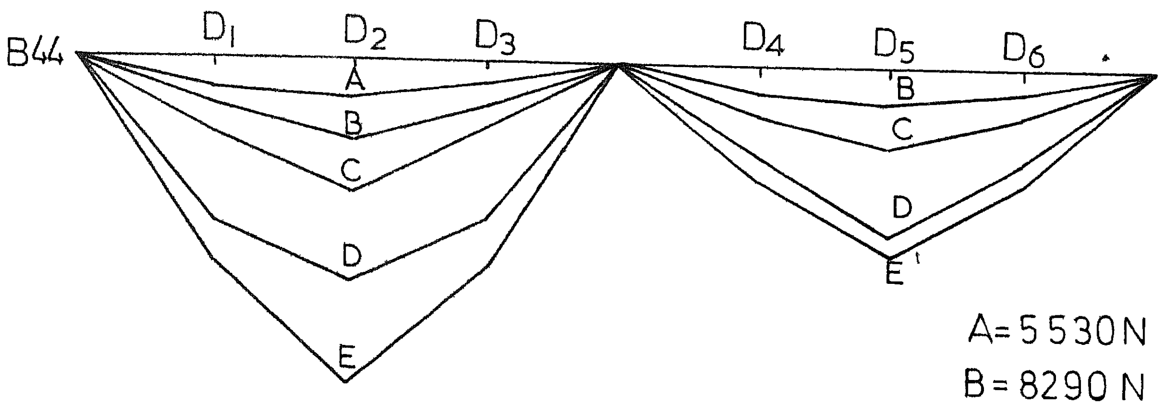


FIG. 3.9 DEFLECTION PATTERN

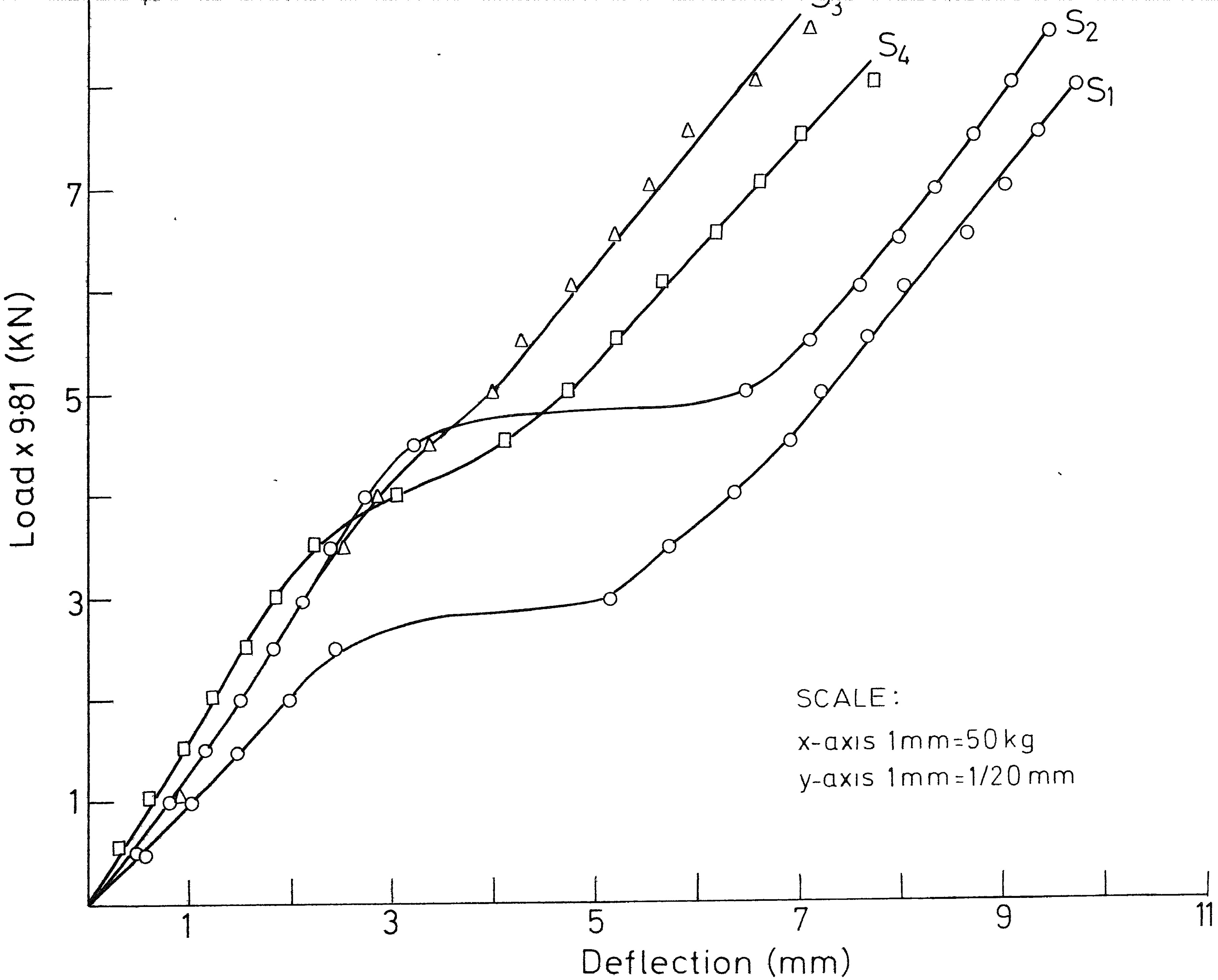


(d)

x-axis 1mm= 20mm.
y-axis 1mm= 1/5 mm

A= 5530N
B= 8290 N
C= 11055N
D= 14740N
E= 16580N

FIG.39 DEFLECTION PATTERN



FIG·3·10(a) LOAD-DEFLECTION CURVE

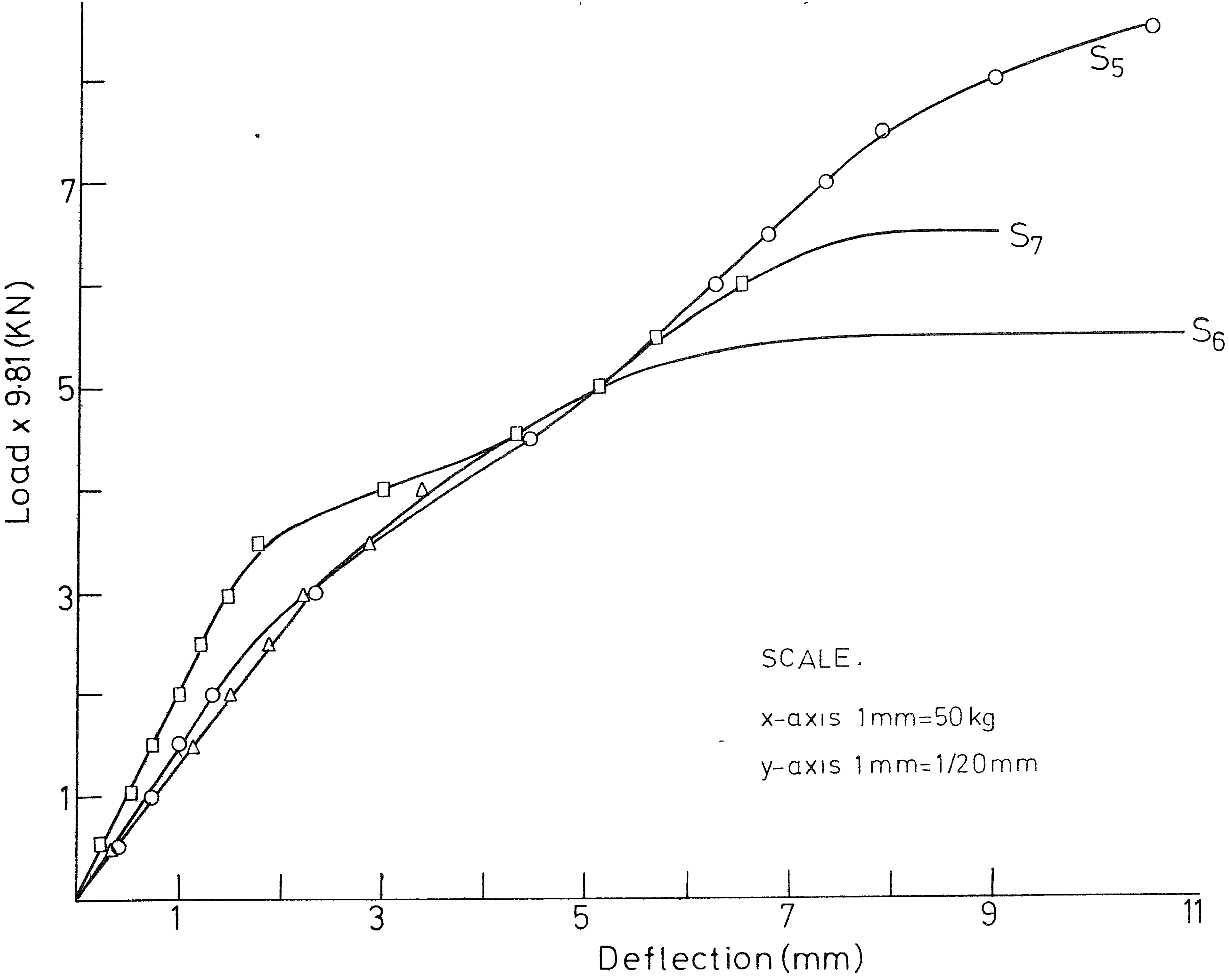
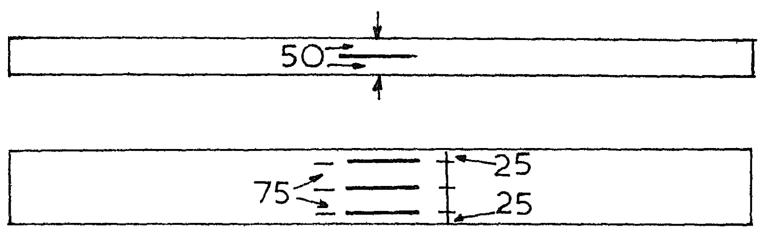


FIG-3-10(b) LOAD-DEFLECTION CURVE



LOCATION OF STRAIN GAUGES

FIG. 3.12

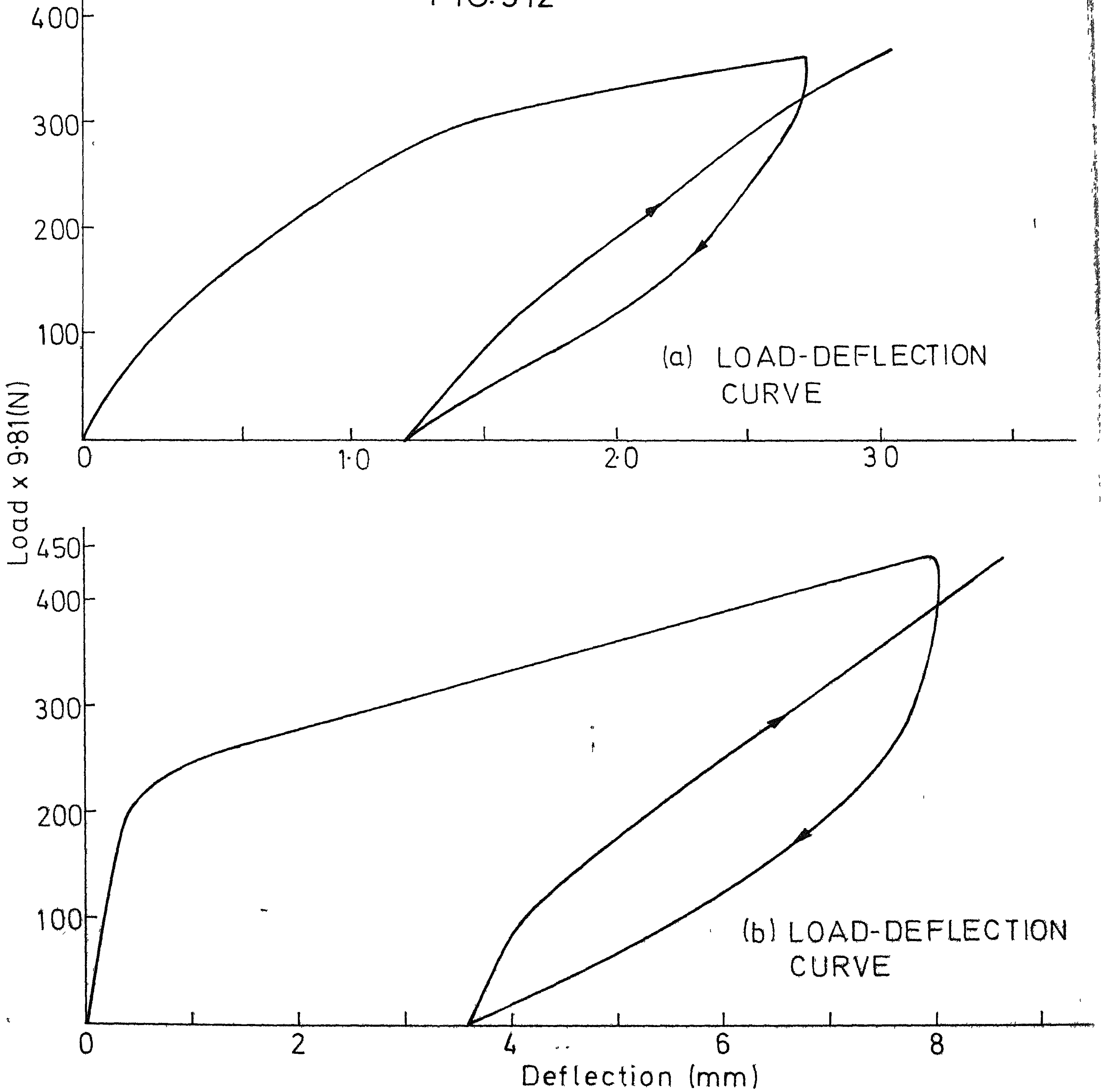


FIG. 3.13

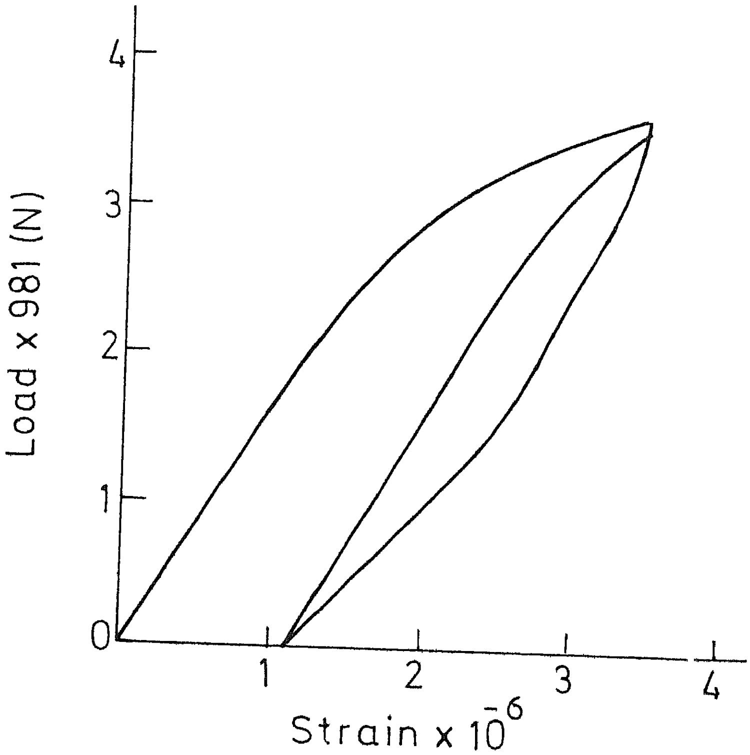


Fig.3·14 Load-strain (max compression) diagram

4. ANALYSIS AND DESIGN OF BEAMS AND SLABS

4.1 General:

In the limit state method of design a structure is proportioned in such a way that it is safe against all modes of collapse, besides satisfying the serviceability requirements as limiting deflection, crack width etc. The ultimate moment of resistance of a section is based on the following assumptions.

(i) The strains in the materials are derived by assuming that plane sections remain plane.

(ii) The stresses in the bamboo reinforcement and the concrete are derived by using stress-strain curves shown in Figs. 2.3 and 2.5 respectively. The failure strain in concrete at the extreme compression fibre is taken as 0.0035. The yield strain in bamboo is taken as 0.008.

(iii) The tensile strength of concrete is neglected.

(iv) The stresses in the reinforcement are determined from the stress-strain curve shown in Fig. 2.3.

4.2 Ultimate Moment of Resistance:

Consider a singly reinforced rectangular beam section shown in Fig. 4.1(a). The following notation is adopted.

h = overall depth of the section

d = effective depth (depth to the centre line of the bamboo)

b = breadth of the section

x = depth to the neutral axis

A_b = area of bamboo in tension

ε_c = strain in concrete

ε_b = strain in bamboo

F_b = stress in the bamboo in tension

F_{cu} = ultimate stress of concrete in compression

The strain diagram and the corresponding rectangular parabolic stress diagram are shown in Fig. 4.1 bade respectively.

4.2.1 Balanced section:

For a balanced section (simultaneous yielding of concrete and bamboo) the depth of the neutral axis x is found to be 0.304 d. The corresponding stresses in concrete and bamboo are 0.45 F_{cu} and $F_b/1.15$ (113 N/mm^2) respectively. The moment of resistance (M_{Rc}) of the section is the compression or tensile force (C or T) in the section multiplied by the lever arm (the distance between the resultant of the forces). From the Fig. 4.1 it can be seen that

Compressive force $C = K_1\ bx$ (4.1)

where, $$K_1 = \frac{\alpha\ F_{cu}}{\varepsilon_c} \left(\varepsilon_c - \frac{\varepsilon_o}{3}\right) \qquad (4.2)$$

C acts at a distance K_2x from the edge of the beam in compression

$$K_2 = \frac{(2-(\varepsilon_o/\varepsilon_c))^2 + 2}{4\ (3-(\varepsilon_o/\varepsilon_c))} \qquad (4.3)$$

where, ε_o is the strain at the intersection of the parabolic and the rectangular part of the stress diagram ($\varepsilon_o = \sqrt{F_{cu}}/5000$) and α is a factor that takes the ratio between the direct compressive stress and the flexural stress and the partial safety factor used for concrete ($\alpha = 0.45$).

These expressions are derived from the dimensions of the stress block (Fig. 4.1 c) using the geometrical properties of the parabola and rectangle.

The moment of resistance M_{Rc} is given by

$$M_{Rc} = C * Z$$

$$= K_1\ bx * (d - K_2x) \qquad (4.4)$$

where,

$$x = \left(\frac{\varepsilon_c}{\varepsilon_c + \varepsilon_b}\right) d = 0.304\ d \qquad (4.5)$$

The tensile force $T = \beta\ F_b\ A_b$

(where β is partial safety factor and is equal to 0.87)

Equating the compressive force C and the tensile force T the area of reinforcement A_b is given by

$$A_b = \frac{C}{0.87\ F_b} \qquad (4.6)$$

4.2.2 Under reinforced section:

In most cases the dimensions of the section are preassigned and the problem is to determine the reinforcement area to resist a given moment. In under reinforced sections the depth of the neutral axis is less than that of the balanced section. By varying nuetral axis depths, moments and areas of reinforcement could be computed. The design charts can be prepared for a particular concrete mix and reinforcement. The design charts are drawn as shown in Fig. 4.2 for M_{15}, M_{20} and M_{25} concrete mixes and the locally available bamboo with a yield strength of 130 N/mm^2. The following is the step by step procedure adopted in the preparation of design charts.

(i) From the strain diagram (Fig.4.1) for different strains in concrete (less than the ultimate strain) calculate the neutral axis depth x using equation(4.5).

(ii) Using equation(4.2) calculate K_1.

(iii) Compute the compressive force $C = K_1\ bx$

(iv) Using equation (4.3) calculate K_2.

(v) The lever arm $Z = d - K_2 x$.

(vi) Compute the moment of resistance $M_{Rc} = C\ Z$

(vii) Equate $C = T$

(viii) Using equation (4.6) calculate A_b

(ix) Find M/bd^2 and A_b/bd

(x) Draw the graph between M/bd^2 versus percentage of A_b/bd

4.2.3 Over Reinforced Sections:

In the case of over reinforced beams the neutral axis shifts towards the tension force from the balanced section. The depths of the neutral axis are computed for various strains (less than the yield strain) in the bamboo. The design charts are drawn following the same procedure described in Article 4.2.2. The design chart is shown in Fig. 4.2.

4.3 Shear Resistance in Beams:

Shear forces accompany changes in bending moment in beams and give rise to diagonal tension in the concrete, and bond stresses between the reinforcement and the concrete. In the elastic analysis, it is assumed that uniform shear stresses act on vertical sections of the beam and the shear resistance of the reinforcement is neglected. For the cracked section the position is much more complicated than the one described earlier.

The shear force is resisted by :

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(i) Uniform shear stresses in the compression zone ,

(ii) aggregate interlocking along the cracks and

(iii) dowel action in the bars where the concrete between the cracks transmits shear force to the stiles.

Similar to the formula derived in the elastic theory the shear stress v is given by

$$v = \frac{V}{bd} \qquad (4.7)$$

where, V is the shear force acting at a section.

The ultimate shear stress v_c depends on concrete grade and percentage of tensile reinforcement. Increase in the amount of tensile reinforcement increases the load needed to cause shear cracking. Thus the large amount of reinforcement increases the depth of the uncracked concrete and so the capacity of concrete in shear. If v exceeds v_c the shear reinforcement is provided by bamboo stiles which cross the cracks.

4.4 Local Bond:

It is assumed in the analysis of reinforced concrete members that no slip occurs between the concrete and the reinforcement. Local bond stresses occur at sections of beams subjected to shear where the force in tension reinforcement is changing along its length. It is necessary

to check that the local bond stresses are not excessive. The bond stress F_{bs} is given by

$$F_{bs} = \frac{V}{\Sigma\ U_b d} \qquad (4.8)$$

where, V and ΣU_b are shear force and perimeter of the reinforcement provided at a section. The critical sections for local bond are simply-supported ends of members, points where tensile reinforcement ends and at points of contra-flexure.

4.5 Limit State Deflection:

4.5.1 Deflection:

The appearance may cause psychological discomfort to the users even the structural efficiency may be lowered. The finishes may spal off. Hence the deflections are to be contained. As a structure ages, the deflections may go on increasing because of creep caused by the sustained loads on the structure. Hence these should be limits priscribed on the short-term and long-term deflections. Essentially the computation of deflections are same for both deflections except that the young's modulus used in the long-term deflections is $\frac{1}{(1+C_c)}$ times the one used for short-term deflections. Where C_c is the creep coefficient. The deflections are computed for cracked and uncracked sections.

The load deflection curves (Fig. 3.5a) are usually bi-linear because the concrete cracks at relatively low tensile stresses.

The expression for the maximum deflection Y_{max} is given by

$$Y_{max} = K_d L^2 \phi \qquad (4.9)$$

K_d = constant depending upon the geometry of the beam

L = effective span of the beam

ϕ = curvature of the beam.

4.5.2 Cracked section:

(i) Strains are calculated on the assumption that plane sections remain plane.

(ii) The reinforcement is elastic with the modulus of elasticity E_b of 16.25 KN/mm^2.

(iii) The stiffening effect of concrete in the tension zone is allowed for by assuming that concrete develops some stress in tension. The value of this stress F_{ct} is taken as zero at the neutral axis and varied linearly to a value of 1 N/mm^2 at the centroid of the tensile reinforcement for short term loads, reducing to 0.55 N/mm^2 for long-term loads.

To demonstrate the method for calculating the curvature consider a singly reinforced beam as shown in Fig. 4.3(a) .

Based on the assumptions above the strain diagram, the stresses and internal forces in the cracked section and the stresses and force due to tension in the concrete are as shown in Fig. 4.3 (b through d) respectively. The exact solution to determine the depth to the neutral axis and the concrete stress would be found by equating the sum of the internal forces to zero and the sum of the moments of these forces about the neutral axis to zero. A solution by successive trials could be adopted.

The problem can be made simple with little sacrifice in accuracy by determining the neutral axis depth for cracked section only using the transformed area method. Referring to transformed section shown in Fig. 4.3(e) the depth to the neutral axis was obtained by taking moments about X-X axis to give the equation

$$\frac{1}{2}\, b\, x^2 = m\, A_b\, (d-x) \qquad (4.10)$$

where, m is the modular ratio between bamboo and concrete and A_b is the area of bamboo.

The moment of inertia of the transformed section about the X-X axis is

$$I_{xx} = \frac{bx^3}{3} + m\, A_b (d-x)^2 \qquad (4.11)$$

The stiffening effect of concrete in the tension zone is now taken into account by calculating its moment of resistance

about the X-X axis. Referring to Fig. 4.3(d) F_{ct} is the tensile stress in concrete at the centroid of the bamboo. F_{ct} $(h-x)/(d-x)$ is the tensile stress at the outer fibre.

$$T_c = F_{ct} b\ (h-x)^2 \ / \ (2(d-x)) \tag{4.12}$$

The moment of resistance of the concrete in tension is given by

$$M_c = 2/3 * T_c(h-x) \tag{4.13}$$

This moment is reduced from the applied moment to give a reduced moment , M_R

$$M_R = M - M_c \tag{4.14}$$

The compressive stress in the concrete F_c is given by the bending formula

$$F_c = \frac{M_R \ x}{I_{xx}} \tag{4.15}$$

The compressive strain ε_c in concrete is given by

$$\varepsilon_c = F_c/E_{cb} \tag{4.16}$$

where, E_{cb} is the modulus of the composite and depends on whether the loads are of short-term or long-term duration. The curvature ϕ is given by

$$\phi = \varepsilon_c/x \tag{4.17}$$

4.5.3 Uncracked section:

The concrete and bamboo both are considered to be

elastic in tension and compression. The modulus of elasticity for bamboo was taken as 1.625×10^4 N/mm^2 in tension.

An uncracked section, strain diagram, transformed section were shown in Fig. 4.4(a through c) respectively. The section is analysed to find out neutral axis depth, the stresses and the curvature. Referring to transformed section shown in Fig. 4.3(c) the equivalent area A_e is given by

$$A_e = bh + (m-1)\ A_b \tag{4.18}$$

The location of centroid was obtained by taking moments of all areas about the top face and dividing by A_e

$$x = \left(\frac{bh^2}{2} + (m-1)\ (A_b d)\right) /\ A_e \tag{4.19}$$

The moment of inertia I_{xx} is given by

$$I_{xx} = \frac{bh^3}{12} + bh\ \left(\frac{h}{2} - x\right)^2 + (m-1) A_b (d-x)^2 \tag{4.20}$$

The stress in concrete in compression F_c is given by

$$F_c = \frac{M*x}{I_{xx}} \tag{4.21}$$

The curvature $\emptyset$ is given by

$$\emptyset = \frac{F_c}{E_c b^x} \tag{4.22}$$

4.5.4 Long-Term Curvature:

The total long-term curvature of a section is assessed by the following three step procedure (1972-9).

(i) Calculate the instantaneous curvatures under the total load and under the permanent load.

(ii) Calculate the long term curvature under permanent load

(iii) Add to the long-term curvature under the permanent load, the difference between the instantaneous curvatures under the total and permanent load .

4.6 Plastic Collapse Load :

The load at which uncontained plastic flow occurs is known as the plastic collapse load. A statically determinate structure collapses as soon as the critical section has attained its moment capacity. For statically indeterminate structures redistribution of moments takes places till the structure degenerates into collapse mechanism. The collapse loads of structures can be computed by applying the upper-bound theorem of plastic analysis (1965-11; 1972-11).

The structures considered in this thesis are simply supported beams subjected to two equal concentrated loads at third points, two-span continuous beams subjected to concentrated loads at mid-span and simply supported square slabs subjected to uniformly distributed loads. These structures

together with the collapse modes are shown in Figs. (4.5, 4.6 and 4.7) respectively.

The collapse loads are given by

Simply-supported (Fig.4.5b): $P_u = 4.5 \dfrac{M_o}{L}$ (4.23)

Two-span continuous beam (Fig.4.4b): $P_u = 2(2+\alpha)\dfrac{M_o}{L}$ (4.24)

Simply-supported square slab (Fig.4.5c):

$$p_u = 24 \frac{M_o}{L^2} \qquad (4.25)$$

(Fig. 4.5d) $$p_u = 22 \frac{M_o}{L^2} \qquad (4.26)$$

where P_u and p_u are the collapse loads of the beams and slabs respectively. M_o and αM_o are the positive and negative moment capacities and L is the span.

The foregoing equations (4.23 through 4.26) are used to compute the theoretical collapse loads shown in Table 4.1.

4.7 Typical Calculation for Rectangular Concrete Beam(B_5)

4.7.1 Moment of resistance (M_o):

Moment of resistance of a singly reinforced rectangular section shown in Fig. 3.1 is as follows:

Data:

Width of the section, b = 100 mm

Overall depth , h = 200 mm

Effective depth, $d = 175$ mm

Area of reinforcement, $A_b = 280$ mm^2

Nondimensional quantity, $\frac{100\ A_b}{bd} = 1.6$

(percentage of reinforcement)

The value of M/bd^2 is read from Fig. 4.2 for the percentage reinforcement ($100\ A_b/bd$) computed above.

$M/bd^2 = 1.56$

Hence the moment of resistance of the section (ultimate moment capacity)

$$M_o = 1.56 \times 100 \times 175^2 \text{ (N-mm)}$$
$$= 4.778 \text{ (KN-m)}$$

4.7.2 Collapse load P_u:

Collapse load of a simply supported rectangular concrete section is calculated using equation (4.23):

Data:

Span, $L = 1800$ mm

Ultimate moment capacity, $M_o = 4777500$ N-mm (from Article 4.7.1)

$$\text{Collapse load } P_u = 4.5\ \frac{Mo}{L} = 4.5 \times \frac{4777500}{1800} = 11943.75 \text{ N}$$

$$P_u = 11.944 \text{ KN}$$

4.7.3 Deflection:

A typical calculation for short-term deflection is

as follows:

Data:

Breadth, $b = 100mm$

Effective depth, $d = 175mm$

Area of bamboo, $A_b = 280\ mm^2$

Modular ratio, $m = \frac{E_b}{E_c} = 0.931$

Tensile stress in concrete $F_{ct} = 1\ N/mm^2$

(at the centroid of reinforcement)

Moment resisted by section, $M = 5734000$ N-mm(as read from Fig. 3.5(b))

Curvature calculation for cracked section:

Neutral axis depth, x is calculated using equation (4.10)

$$\frac{1}{2} bx^2 = m A_b (d-x)$$

$$50 x^2 = 0.931 \times 280 (175-x)$$

$$x = 27.73 \text{ mm}$$

The moment of inertia, I_{xx} is calculated using equation (4.11)

$$I_{xx} = \frac{bx^3}{3} + m A_b (d-x)^2$$

$$I_{xx} = \frac{100 \times 27.73^3}{3} + 0.931 \times 280 (175 - 27.73)^2$$

$$= 6.37 \times 10^6 \text{ mm}^4$$

Tensile force resisted by concrete in tension zone, T_c, is obtained by using equation (4.12)

TABLE 4.1: COMPARISON OF THEORETICAL AND EXPERIMENTAL RESULTS

Specimen No.	Area of Reinforcement (A_b) (mm^2)			Moment Capacity (M_o) In Case of Beams (KN-m) In case of Slabs (KN-m/m)		Collapse Loads (KN)		Deflection (mm)	
	Positive		Negative	Positive	Negative	Theoretical	Experimental	Theoretical	Experimental
B_1	332	-	-	5.665	-	14.150	11.750	14.90	18.60
B_2	344	-	-	5.910	-	14.780	12.250	16.00	20.40
B_3	278	-	-	4.900	-	12.250	11.500	17.40	24.85
B_4	340	-	-	5.895	-	14.740	12.120	13.00	17.40
B_5	280	-	-	4.775	-	11.945	11.970	15.10	26.85
B_6	350	-	-	5.300	-	13.225	11.250	12.45	22.10
B_7	440	-	-	5.705	-	14.250	11.770	10.70	21.30
B_8	384	-	-	5.330	-	13.320	11.560	11.50	19.70
B_{11}	312	-	204	5.085	3.830	17.450	17.850	-	-
B_{22}	296	-	195	4.960	3.520	16.800	17.250	-	-
B_{33}	305	-	201	4.990	3.675	17.050	17.400	-	-
B_{44}	309	-	227	5.055	3.920	19.350	21.650	-	-
B_1	640	660	-	2.230	-	53.460	78.500	-	-
S_2	950	960	-	2.975	-	71.425	88.000	-	-
S_3	971	981	-	3.035	-	72.900	88.000	-	-
S_4	1000	1010	-	3.120	-	74.830	83.500	-	-
S_5	970	986	-	2.975	-	71.425	83.500	-	-
S_6	502	521	-	1.690	-	40.550	54.000	-	-
S_7	592	612	-	1.960	-	47.050	63.500	-	-

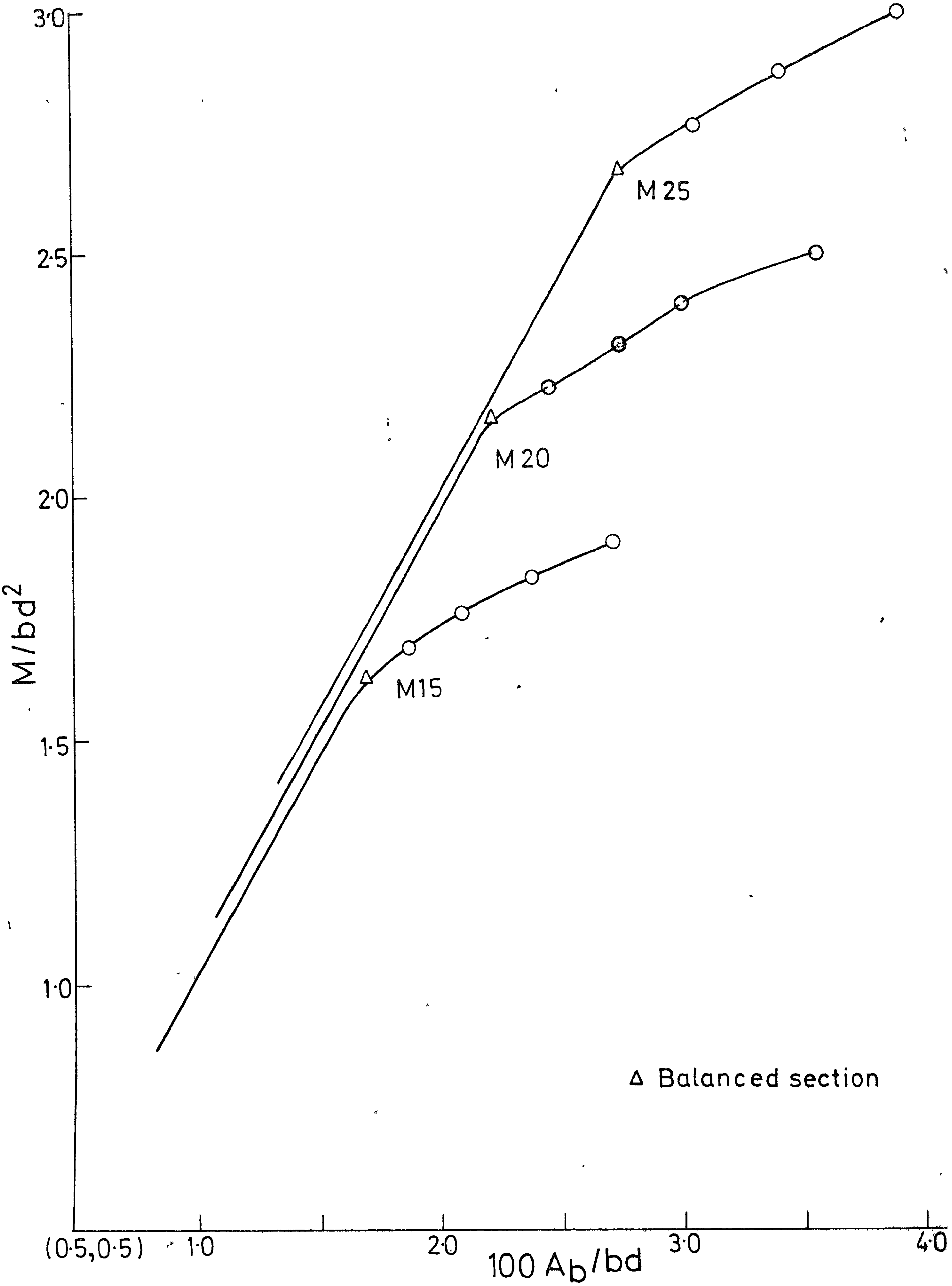
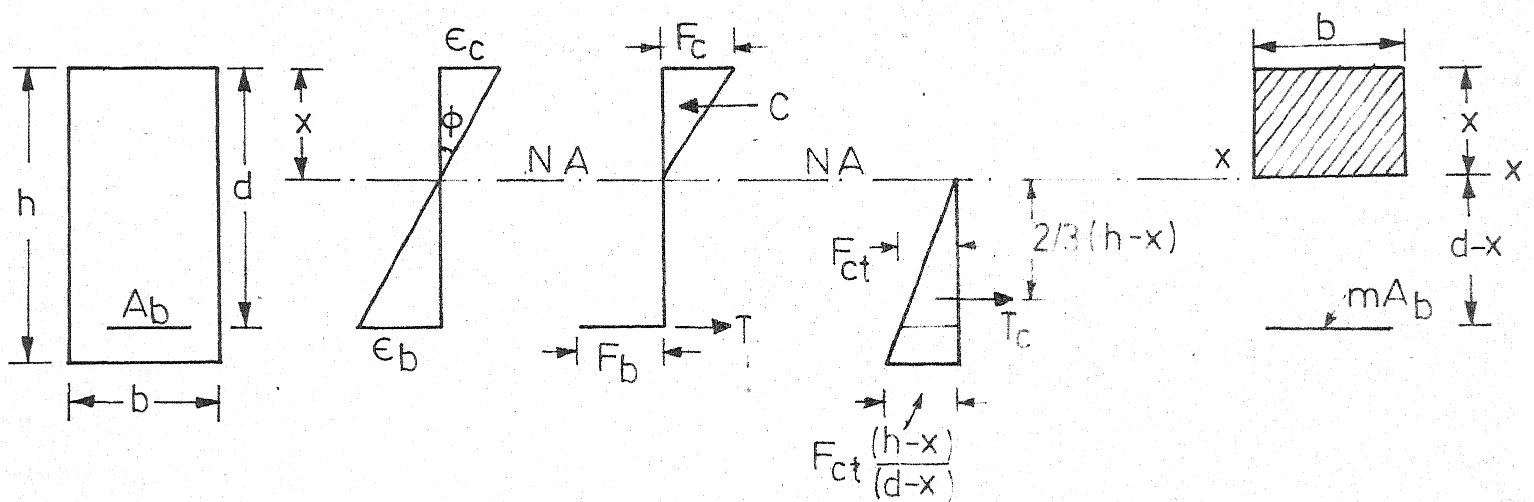


Fig. 4·2 Design charts for singly reinforced section



(a) Section

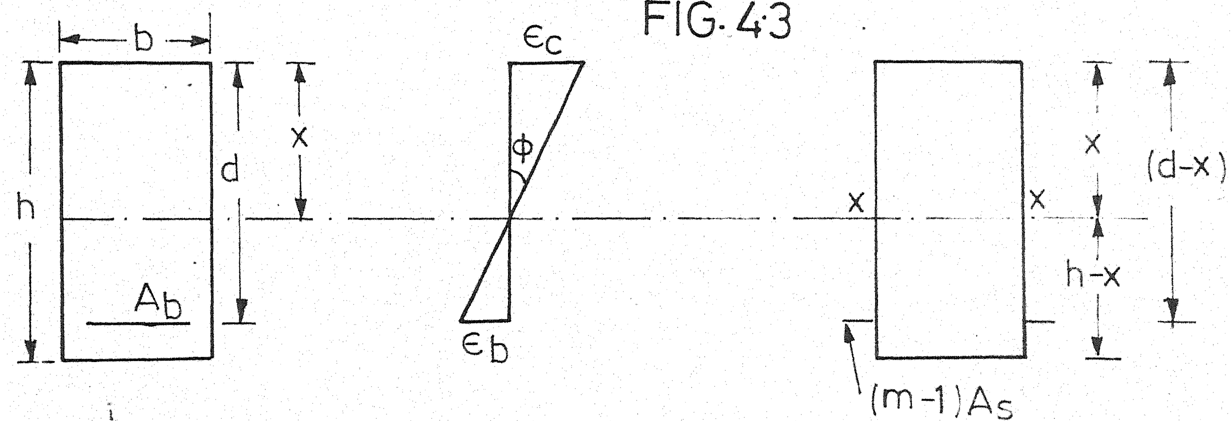
(b) Strain diagram

(c) Forces and stresses in cracked sec.

(d) Tension in concrete

(e) Transformed section

FIG. 4.3

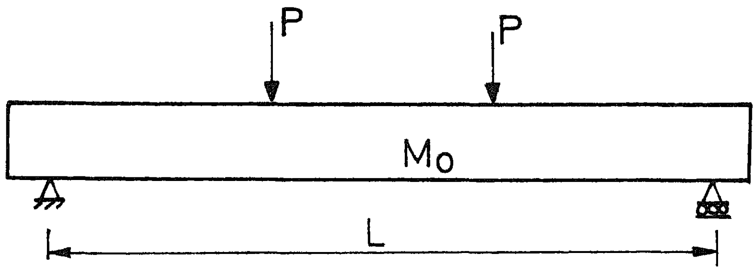


(a) Section

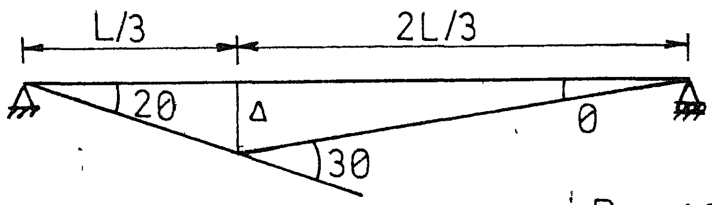
(b) Strain diagram

(c) Transformed section

FIG. 4.4



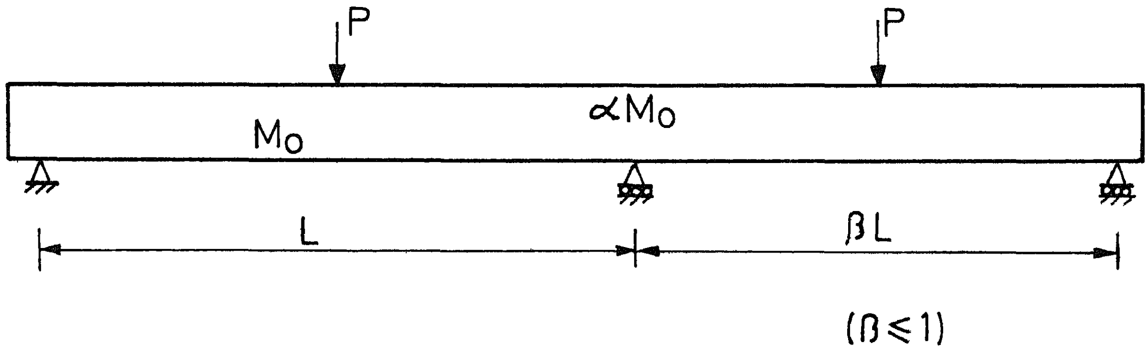
(a) Loading and support conditions



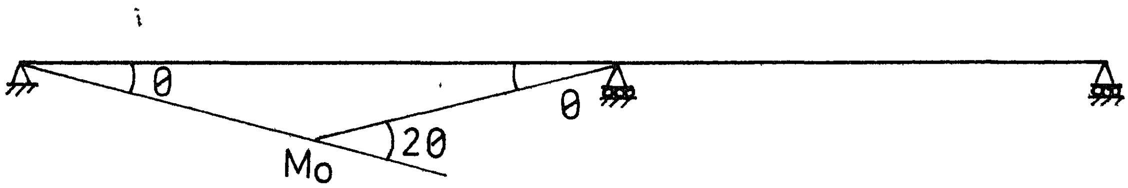
$$P_u = 4.5\,\frac{M_o}{L}$$

(b) Collapse mode

FIG. 4.5



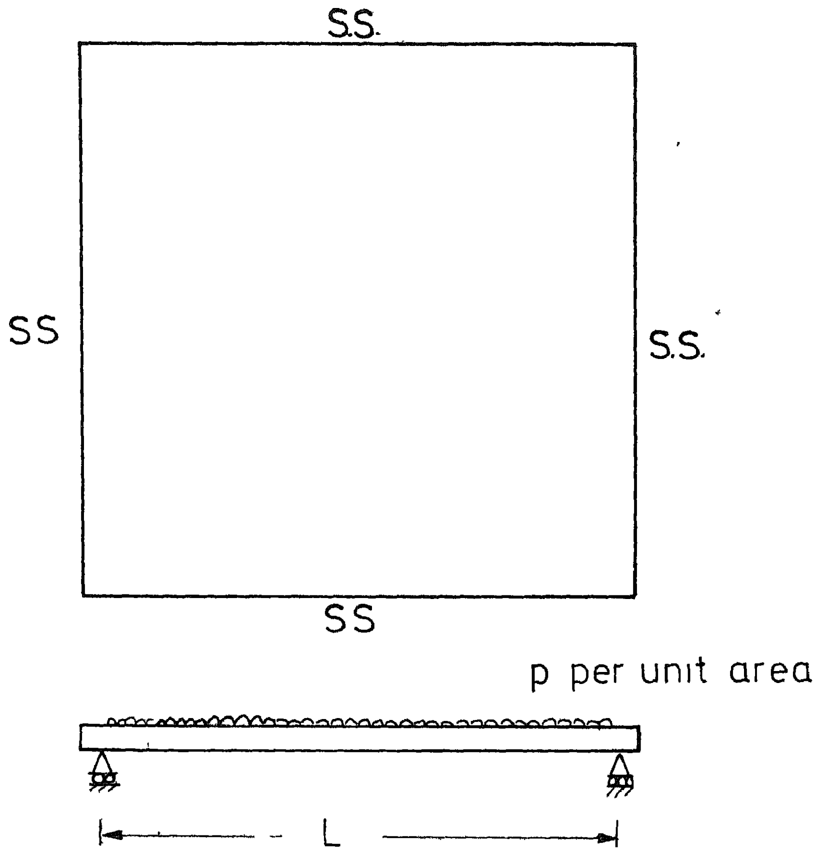
(a) Loading and support conditions



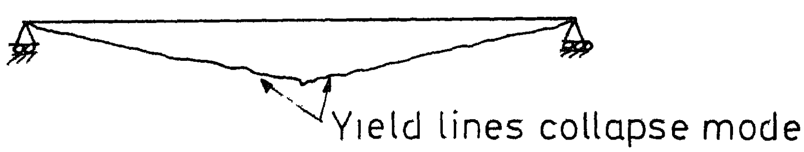
$$P_u = 2(2+\alpha)\,\frac{M_o}{L}$$

(b) Collapse mode

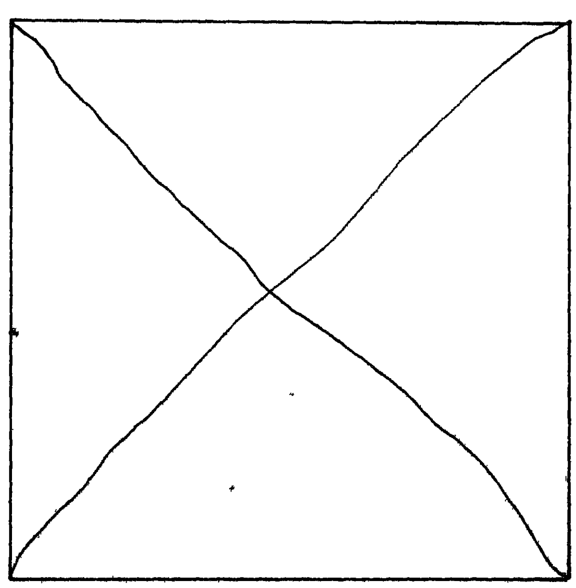
FIG. 4.6



(a) Loading and support conditions



(b)



(c) Collapse mode

ultimate load $p_u = 24 \frac{M_o}{L^2}$

FIG. 4.7

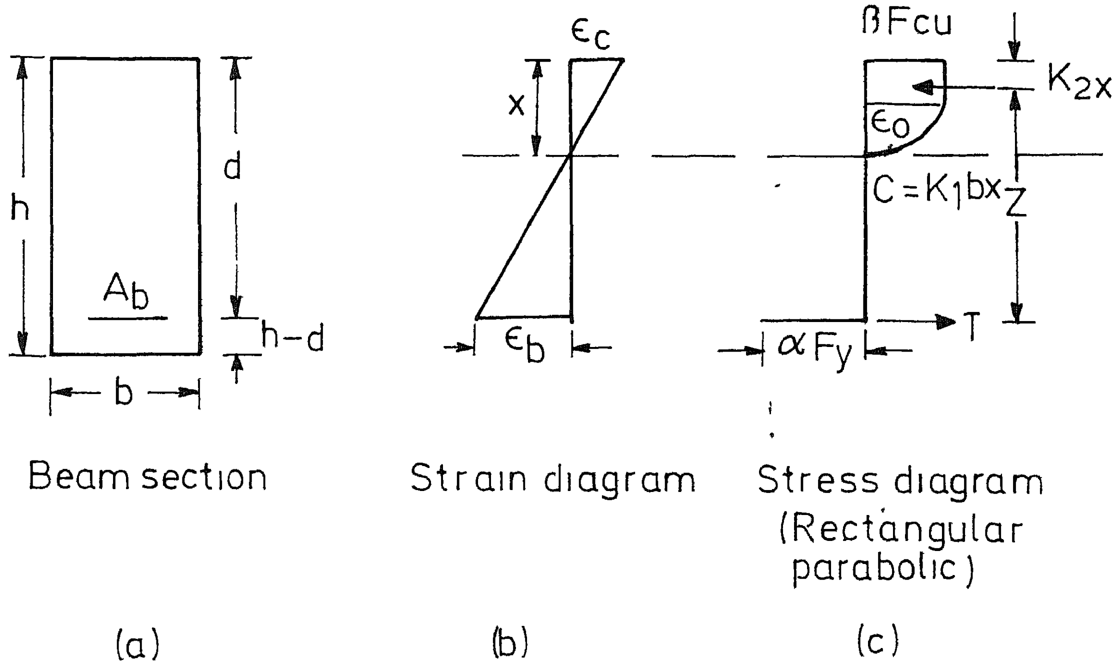
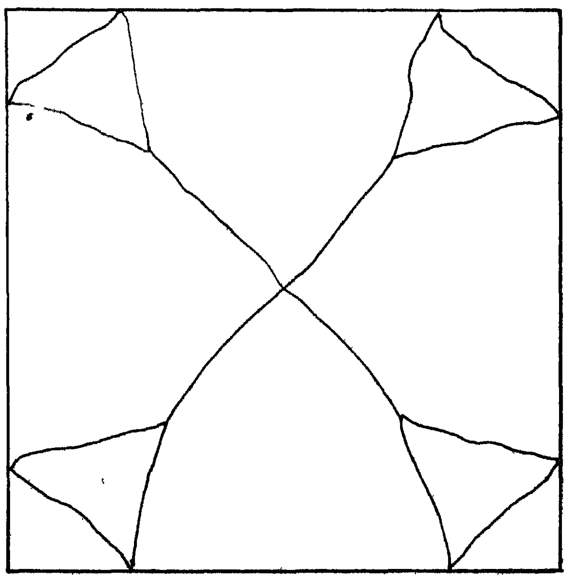


FIG. 4.1



(d) collapse mode

ultimate load $pu = 22 \frac{M_o}{L^2}$

FIG. 4.7(d)

5. CONCLUSIONS

5.1 General:

A number of useful conclusions can be drawn based upon the experimental and theoretical results presented in the earlier chapters.

5.1.1 Material properties:

As bamboo is an organic material grown in all climatic conditions. The variations in mechanical properties are usually considerable . The tensile strength recorded in he literature is as high as 365 N/mm^2 which lies some where in between the yield strength Hot-rolled mild and high yield steels. However the yield strength that is observed in most cases is around 130 N/mm^2. The yield strain in bamboo is 0.008 as compared to 0.0035 of mild steel and concrete. As a result the area of concrete in tension is more than that of steel reinforced sections. The modulus of elasticity of bamboo is about ten percent that of mild steel and almost equal to concrete. Hence the deflections in bamboo reinforced concrete structures will obviously be more than that of the steel reinforced structures. Consequently the crack widths also will play a significant role in the design of bamboo reinforced concrete structures.

5.1.2 Bond Strength:

For each type of bamboo there is a critical length of embedment beyond which no significant increase in bond strength will be realised. The concept of allowable average bond stress should either be completly dispensed with or modified drastically. It is better to introduce a weighted bond stress concept wherein the bond stress along the length of reinforcement will be either a gradually decreasing step-function or a smooth curve. It is also observed that bond strength varies with the shape of the bamboo stile for the same perimeter. The bamboos that are choosen for reinforcement should be such that the diameter to thickness ratio should be large. It is preferable not to chop off the protrutions at the nodes as this will improve the bond strength.

5.1.3 Orientation of bamboo:

The orientation of bamboo stiles will also contribute to the behaviour of the structure. This statement can be substantiated by comparing the load-deflection curves of the beams B_2 and B_4 given in Fig. 3.5(a). Hence it is desirable to orient the bamboo stile in such a manner that the convex face is towards the tension face of the beam.

5.1.4 Effect of moisture:

The volume of bamboo changes with the percentage of moisture content. If proper precautions were not taken, the structure when cast may crack along the bamboo stiles even before the concrete dries up. This has been observed incase of beams as well as slabs. This could be overcome by soaking the bamboo in water prior to the placement of concrete.

5.1.5 Partial safety factor for loads:

The partial factor of safety for loads should be taken as 2.0 insted of 1.5 as recommended for steel reinforced concrete structures. This is true only when the permissible deflections are as per the latter (the span-deflection ratio is 250). The average span-deflection ratio for beams is 250.

5.1.6 Redistribution of moments:

In the case of continuous beams and slabs, the moment and shear envelops should be drawn and the percentage redistribution of moments determined taking the rotation capacity of the sections. The absolute maximum negative moment over the middle support may be reduced to the tune of 15 to 20 percent. This will avoid the formation of wider cracks over the support than those at the mid-spans. For

the continuous beams tested, the cracks formed simultaneously at both the positive and negative moment sections. However, as the collapse load was approached, the cracks at the positive moment section widened at a faster rate than those over the middle support. This can be observed in plate 3.3.

5.1.7 Primary and secondary bond failures:

It can be seen from the results shown in Table 4.1 all the beams failed due to bond failure. This can be visualised from the plates 3.2. In the case of simply supported beamsthe theoretical collapse loads are more than the experimental values by 6 to 17 percents (Table 4.1). In the case of simply supported beams the failure is primarily bond failure whereas in continuous beams the bond failure is secondary in nature. The horizontal cracks shown along the longitudinal reinforcement seen in plate 3.2(a thourgh d) and 3.3 depict the bond failure. This can be avoided by providing large number of thin stiles.

5.1.8 Effect of clear cover:

In case of slabs, the formation of cracks at the early stages of loading is along the directions of the reinforcement (Fig. 3.11 cracks marked one). As the loading is increased further these cracks closeup and new cracks are formed in such a way that the slab collapses approximately

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5.1.8 Effect of clear cover:

In case of slabs, the formation of cracks at the early stages of loading is along the directions of the reinforcement (Fig. 3.11 cracks marked one). As the loading is increased further these cracks closeup and new cracks are formed in such a way that the slab collapses approximately

like that of a square pyramid (Fig. 3.11). The formation of cracks along the reinforcement can be avoided by increasing the clear cover.

5.1.9 Maximum spacing of reinforcement:

In slabs S_1 and S_2 where the reinforcement was placed 290 mm c/c , the width of the cracks widened at faster rate tha those slabs with closely spaced reinforcement (S_3 through S_7). This is due to the fact that the spacing of the reinforcement is more than 3 times the effective depths of the slab. Hence it is desirable that the maximum spacing is limited to 3 times the effective depth as in the case of steel reinforced slabs.

5.1.10 Comparison of collapse loads:

In the case of continuous beams the theoretical values are smaller than the experimental values by 3 to 10 percent. The experimental values are higher than the theoretical values in the case of slabs (some times as much as 40 percent). This is due to the nature of the loading arrangement and likely membrane effect.

5.1.11 Pulsating loads:

The bamboo reinforced structures should preferably be not subjected to dynamic loads. In case of temporary structures, however, the pulsating load may be predetermined as 40 percent of the ultimate load. The beams PB_2 and PB_3

when subjected to loads (upper and lower limits 40 and 10 percent respectively of the ultimate load), behaved reasonably well. The deformations were not large even after 1 million cycles. The beam PB_1 collapsed after 150000 cycles when subjected to an upper limit load of 60 percent of the ultimate load.

5.2 Scope for Further Study:

(1) By mixing about 3 to 5 percent of the bamboo fibres in concrete, the moment capacity of the sections can be increased substantially. This will increase even the stiffness of the structure.

(2) The effect of moisture content on the tensile strength of the bamboo deserves further study.

(3) Short and long-term tests should be conducted on prototype beams and slabs.

(4) The effect of blast loads on the bamboo reinforced structures should be looked into.

5.3 Recommendations:

The bamboo can confidently be used as an expedient material for reinforcing concrete structures that are not primarily subjected to dynamic loads. It is possible to design the bamboo reinforced structures rationally.

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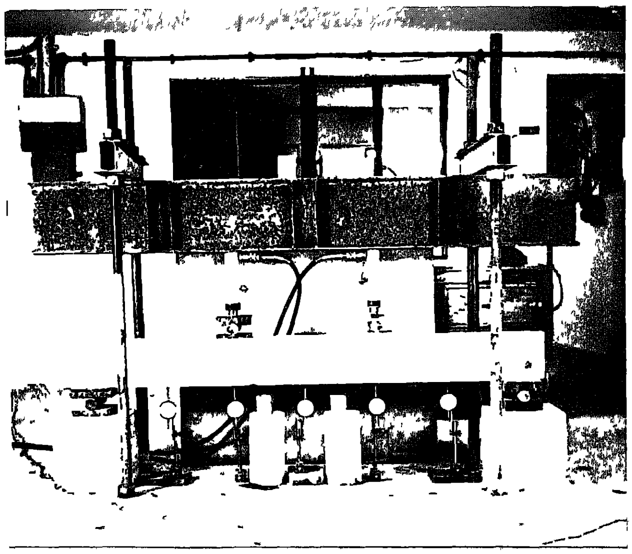


Plate 3.1

Plate 3.2 (a)

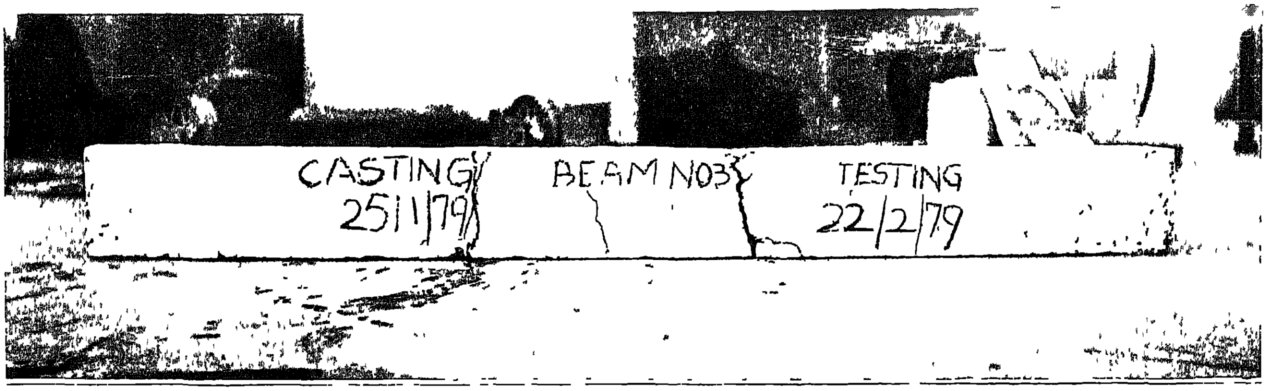


Plate 3.2 (b)

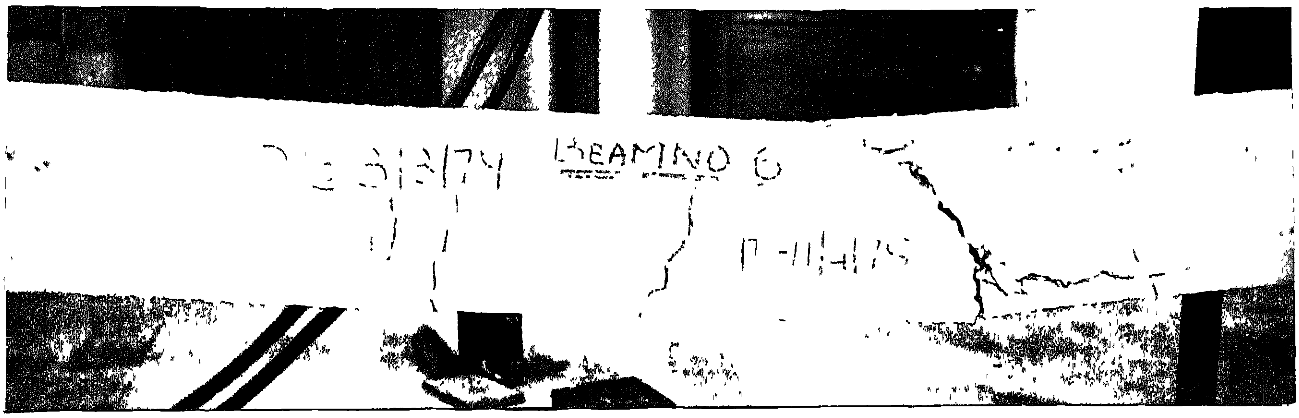


Plate 3.2(c)

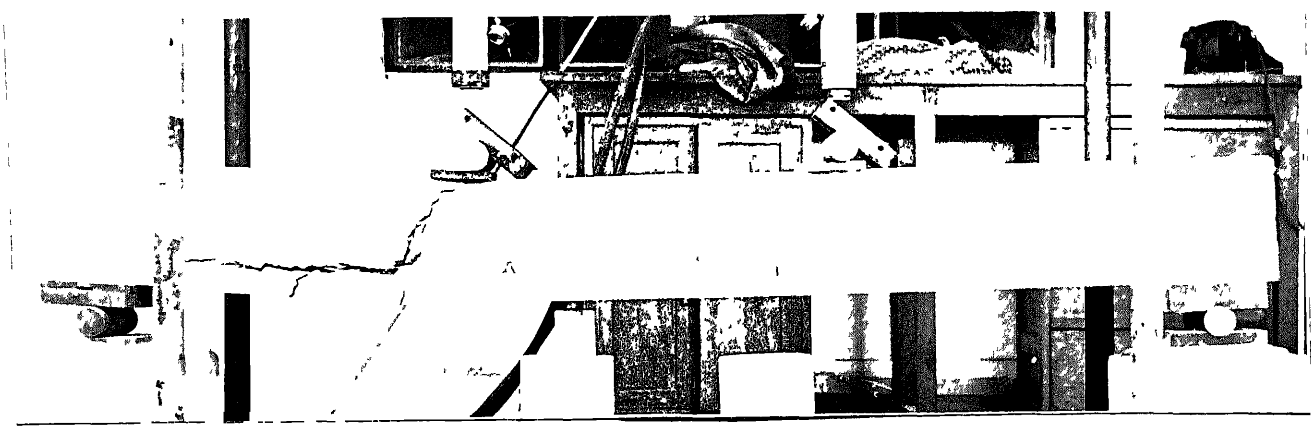


Plate 3.2(d)

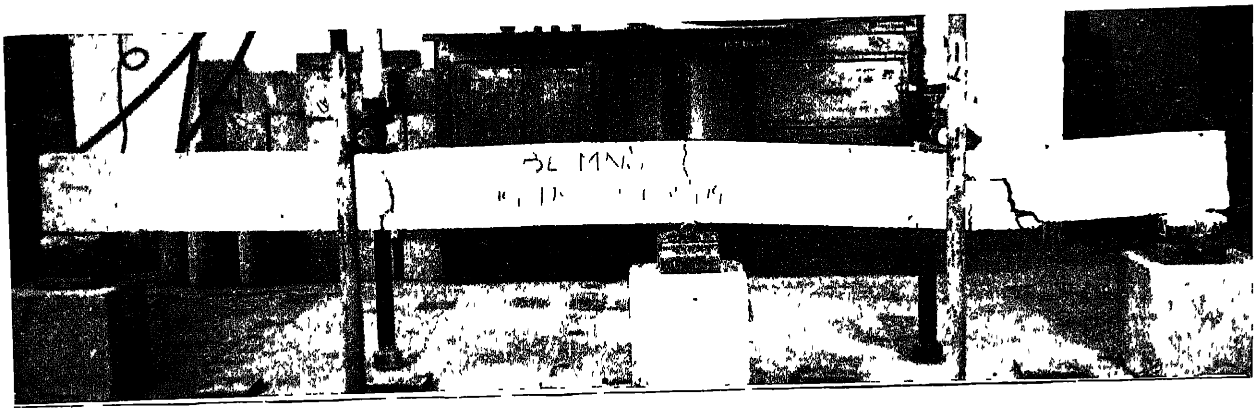


Plate 3.3

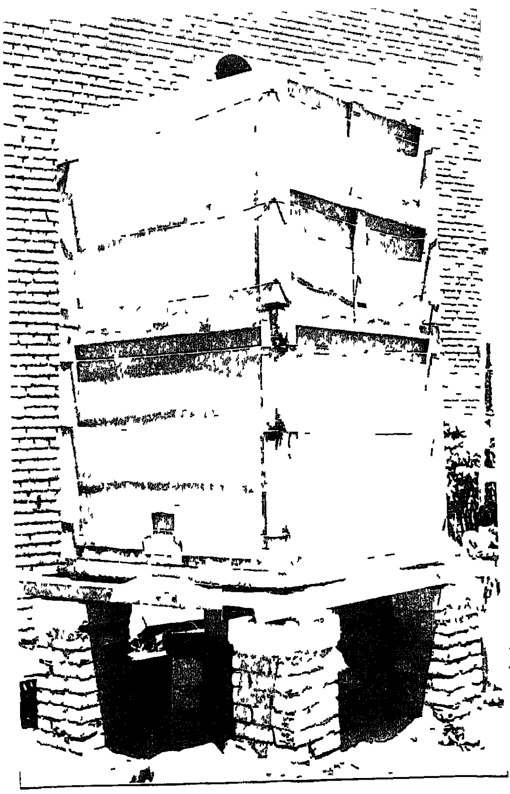
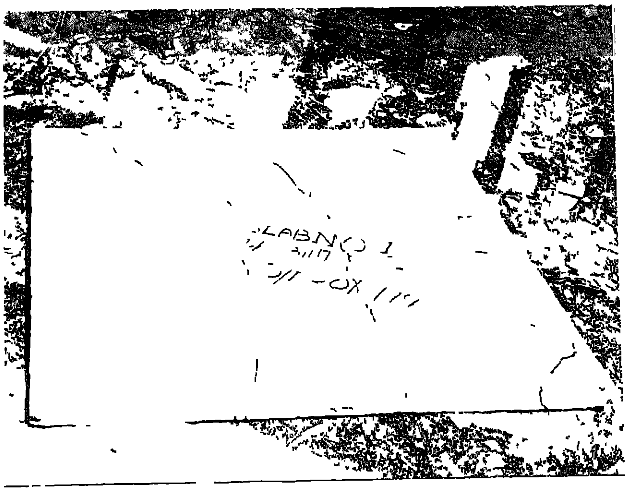
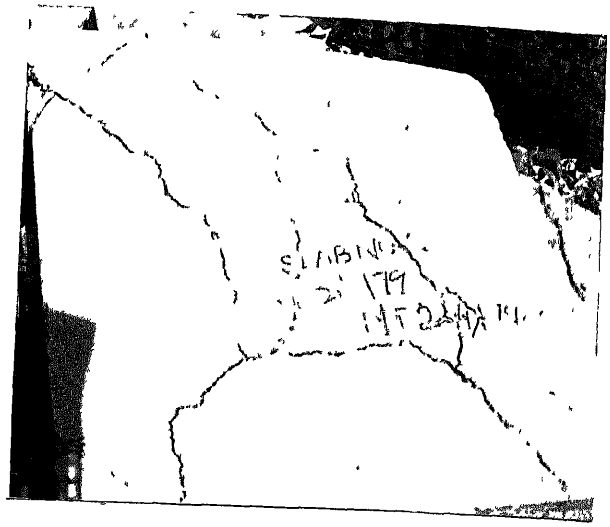


Plate 3.4



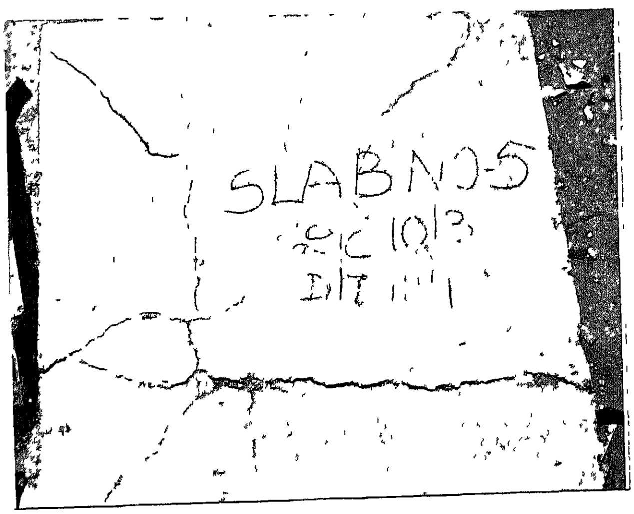
(a)

Plate 3.5



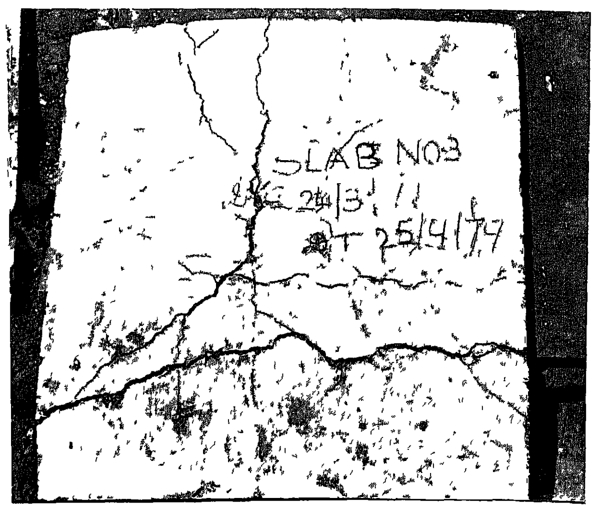
(b)

Plate 3.5



(c)

Plate 3.5



(d)

Plate 3.5